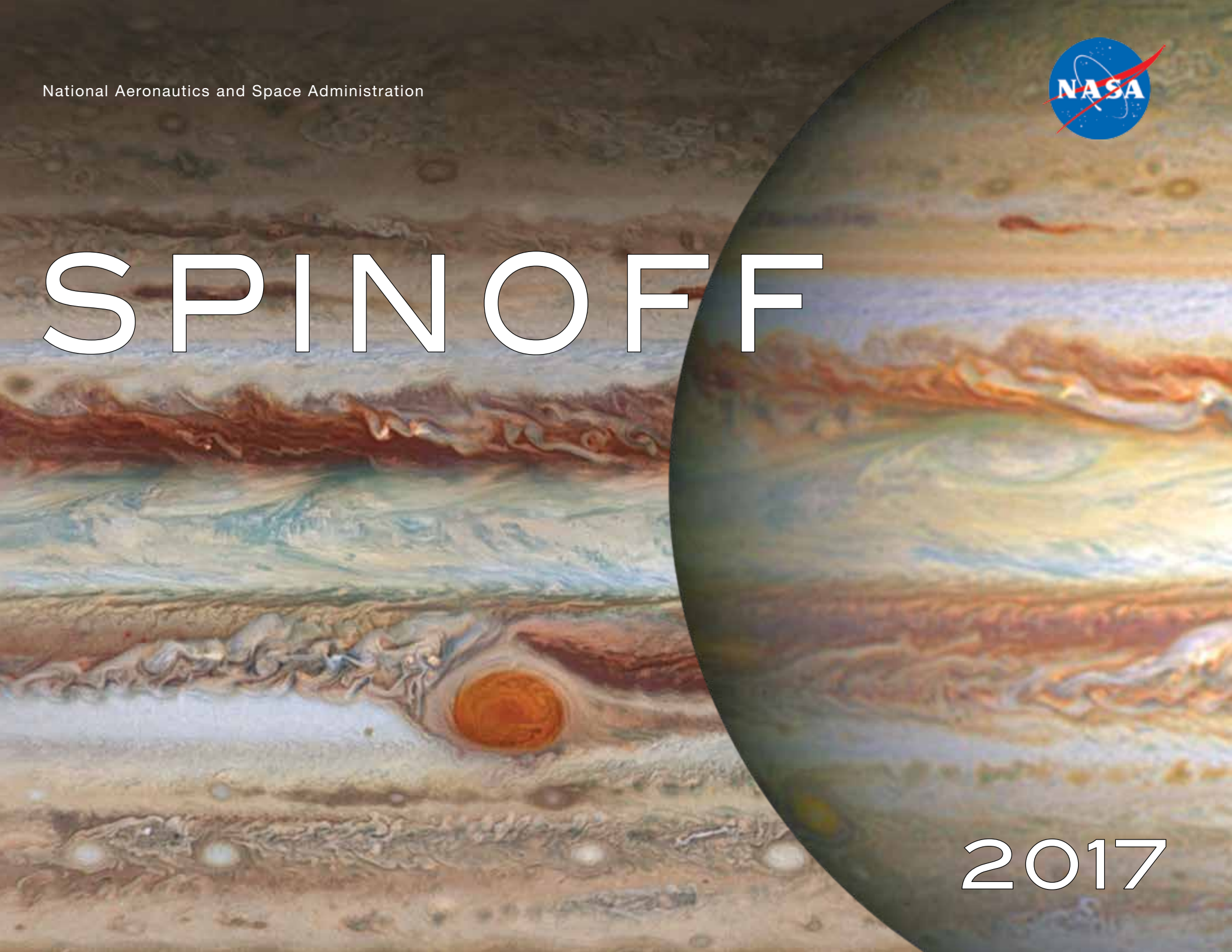
National Aeronautics and Space Administration



SPINOFF

2017

SPINOFF

2017

Technology Transfer Program

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This artist's rendering, based on data from the Hubble Space Telescope, shows water vapor pluming from cracks on the surface of Europa, one of the solar system's most intriguing moons. Tidal forces from Jupiter's immense gravity are believed to cause enough internal friction to heat a stable ocean of liquid water beneath the icy body's surface. The presence of this ocean has led scientists to speculate that Europa may even host life, and a future NASA mission is being planned that would conduct 45 flybys of the moon to gather detailed observations of its habitability.

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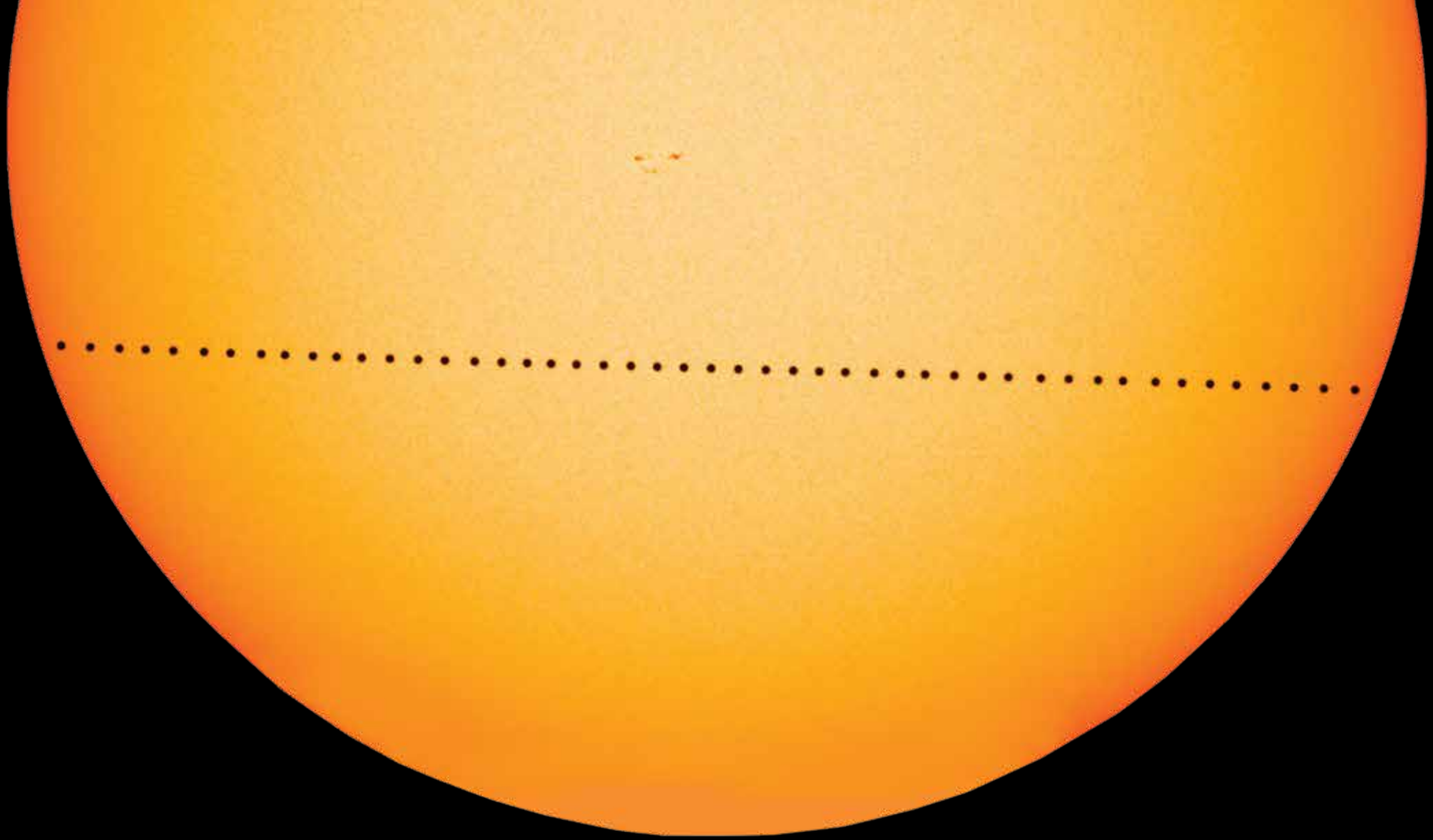


On May 9, 2016, Mercury passed directly between the sun and Earth. NASA's Solar Dynamics Observatory studies the sun 24/7 and captured the entire seven-and-a-half-hour event, and its data was used to create this composite image. Amazingly, exoplanets near the size of Mercury have been discovered orbiting distant stars simply by measuring the amount of light the planets block as they pass between their star and our vantage point.

Foreword

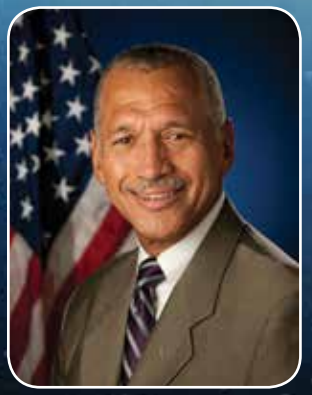
When NASA sets out on a new mission to explore the cosmos, we know the results will often surprise and astonish us. Our most recent far-reaching achievement came with the arrival of the Juno spacecraft at Jupiter this past Fourth of July. The mission promises to give us unprecedented insights into the makeup of the colorful gas giant, as well as clues about how our solar system formed. And it will likely yield technology that improves life on Earth, too (see page 8).

Juno is the latest among a host of probes, landers, rovers, and telescopes that have played a key role in NASA's endeavors to extend humanity's reach into the universe. In just the past several years, using these instruments, we have excavated Martian soil, skimmed through water plumes over Enceladus' fractured surface, discovered more than a thousand planets orbiting other stars, mapped icy mountain ranges on Pluto, and so much more. Each new accomplishment answers fundamental questions of science, capturing the world's imagination and demonstrating the importance of expanding the horizons of our knowledge.

We go to space to explore, and the ultimate achievement in exploration is human missions to new frontiers. In particular, NASA is on a journey to Mars—a journey that will stretch the capabilities and resolve of our Nation. To prepare for the trip, much of the cutting-edge technology being developed by NASA right now is designed to help us put astronauts on the surface of the Red Planet in the 2030s. As we develop these technologies, NASA collaborates with American businesses to do its work. Every dollar spent on technology for space missions is a dollar spent on Earth, benefiting the economy.

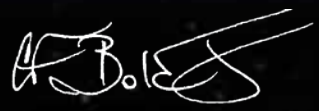
But the Agency also makes sure these innovations go beyond their original uses to benefit the public as widely as possible. These secondary applications can be as surprising as the scientific discoveries made by our spacecraft: as you'll see in the following pages, NASA technologies can be found in your mobile devices, in self-driving tractors that work the fields, and in the latest 3D printers used by makers and hackers. They are making brain surgery safer and spotting rainforest fires before they spread. Spinoffs are even more diverse than the broad array of NASA missions they come from.

This issue of *Spinoff* celebrates our Nation's successes with robotics missions and looks to a future of human spaceflight and planetary exploration enabled by cutting-edge technology—with ever more down-to-Earth benefits sure to follow. I hope it opens your imagination to what's possible, both in space and on Earth, when we set our sights on venturing into the unknown.



Charles F. Bolden, Jr.
Administrator

National Aeronautics and Space Administration



Spinoff (spin´ôf) -noun.

1. A commercialized product incorporating NASA technology or expertise that benefits the public. These include products or processes that:
    - were designed for NASA use, to NASA specifications, and then commercialized;
    - are developed as a result of a NASA-funded agreement or know-how gained during collaboration with NASA;
    - are developed through Small Business Innovation Research or Small Business Technology Transfer contracts with NASA;
    - incorporate NASA technology in their manufacturing process;
    - receive significant contributions in design or testing from NASA laboratory personnel or facilities;
    - are successful entrepreneurial endeavors by ex-NASA employees whose technical expertise was developed while employed by the Agency;
    - are commercialized as a result of a NASA patent license or waiver;
    - are developed using data or software made available by NASA.
2. NASA's premier annual publication, featuring successfully commercialized NASA technologies.

A prototype 13-kilowatt Hall thruster is tested at NASA's Glenn Research Center in Cleveland. This prototype demonstrated the technology readiness needed for industry to continue developing high-power solar electric propulsion into a flight-qualified system.

Introduction

For more than 40 years, NASA's *Spinoff* publication has demonstrated that there's more space in your life than you think, featuring more than 2,000 technologies with origins in space and aeronautics missions that have subsequently benefited our Nation and world.

The stories published in *Spinoff* represent the end of a technology transfer pipeline that begins when researchers and engineers at NASA develop innovations to meet mission needs. NASA employees report more than 1,600 new inventions annually, from hardware to cutting-edge software, and these technologies are captured and assessed by the Agency's Technology Transfer Program. Most are published to notify the public of NASA's work and to encourage public-private partnerships with industry where interests overlap. The Agency patents its inventions with the greatest commercial potential and offers these to American businesses for licensing. Meanwhile, NASA-created software is collected and annually published in a catalog, nearly all of it free to download and use.

In the following pages you can read about 50 NASA *spinoffs*, products and services at work in every sector of the economy. Notable examples include:

- The world's most widely used digital image sensor. The invention traces back to a scientist at NASA who wanted to miniaturize cameras for interplanetary missions. Today, whether you take pictures and videos with a DSLR camera or cell phone, or even capture action on the go with a device like a GoPro Hero, you're using NASA technology. (page 86)
- Self-driving tractors. Beginning in the 1990s, NASA researchers developed software capable of correcting for GPS signal errors, enabling accuracy to within inches. John Deere acquired the technology and used it to develop the world's first widely used self-driving farm equipment. Today, as much as 70 percent of North American farmland is cultivated by self-driving tractors, most of which still rely on technology originally developed at NASA. (page 110)
- Space-ready lidars used by archaeologists. An instrument that discovered snow on Mars has a direct connection to the commercial lidar that helped search for sites where prehistoric North Americans hunted bison herds en masse. (page 136)

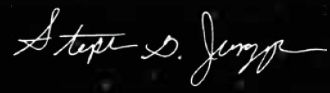
Alongside these mature, fully commercial products, you can also find 20 patented NASA inventions that the Technology Transfer Program has identified as being particularly ripe for use by industry, along with information on how you can acquire these technologies or partner with us to develop them further. (page 206)

Part of NASA's mission, written into the Agency's foundational legislation, is a requirement to "provide for the widest practicable and appropriate dissemination" of the fruits of its scientific and technological discoveries. *Spinoff* 2017 shows that this spirit is alive and well at NASA, and we hope that you enjoy reading about the many ways space exploration yields practical benefits for all of us on Earth.

Stephen Jurczyk

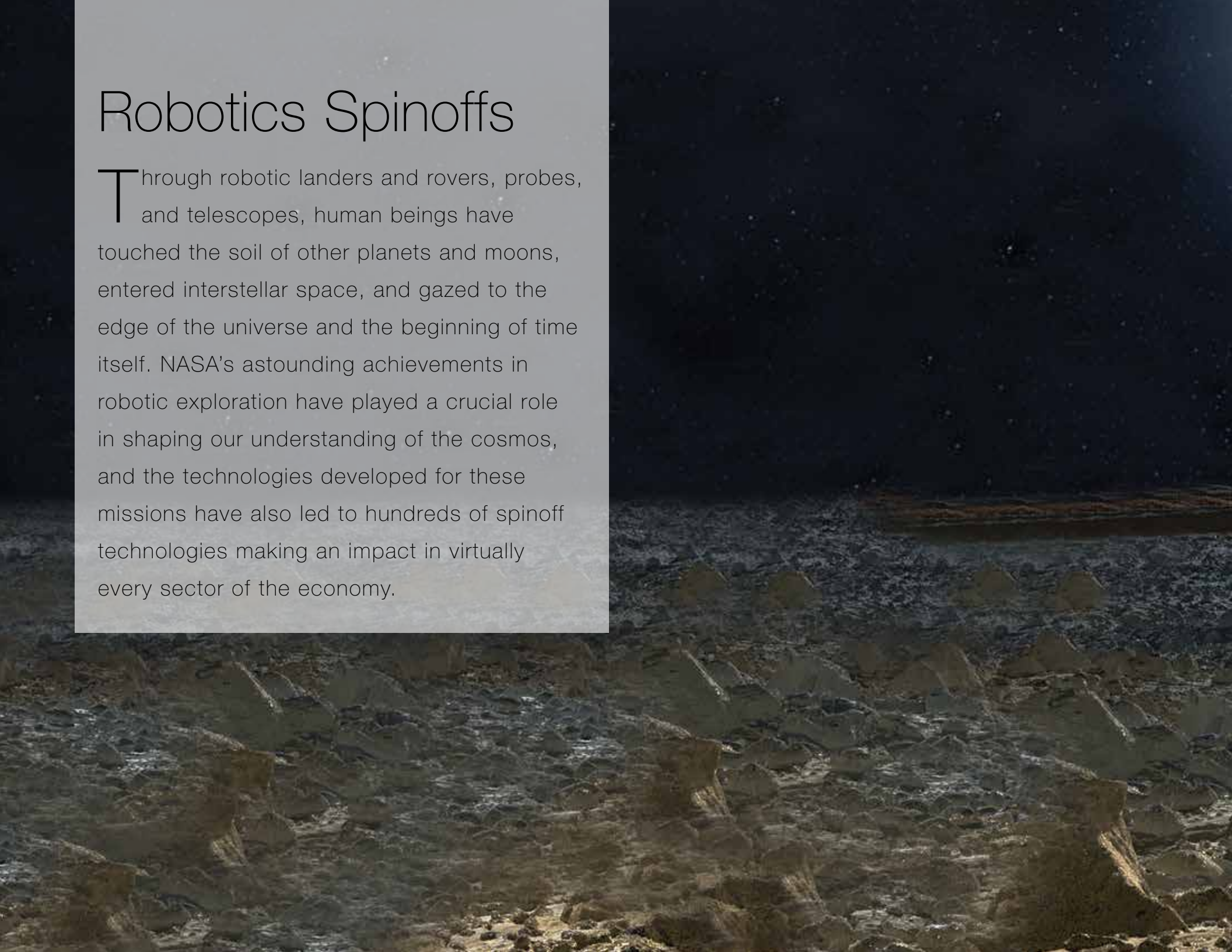
Associate Administrator

Space Technology
Mission Directorate



Robotics Spinoffs

Through robotic landers and rovers, probes, and telescopes, human beings have touched the soil of other planets and moons, entered interstellar space, and gazed to the edge of the universe and the beginning of time itself. NASA's astounding achievements in robotic exploration have played a crucial role in shaping our understanding of the cosmos, and the technologies developed for these missions have also led to hundreds of spinoff technologies making an impact in virtually every sector of the economy.



Into the Void

NASA's robotics missions have uncovered many mysteries of the cosmos—and have led to spinoff benefits for life on Earth as well.

What lies beneath the swirly, colorful exterior of Jupiter? How much water is in its atmosphere? How does the planet's enormous magnetic field affect its surface?

Gas giants like Jupiter were among the first planets to form in our solar system, and understanding more about its composition now will help us understand the earliest stages of its formation and of planets like it.

In ancient days, humans answered their questions about the world with stories of gods and goddesses. The Romans spoke of a mischievous Jupiter, king of the gods, who surrounded himself in a veil of clouds to mask his misdeeds. His goddess wife, Juno, peered through those clouds to reveal his true nature.

In the 21st century, we are still telling stories and asking big questions, but we have new tools to look for the answers. Since its formation nearly 60 years ago, NASA has harnessed cutting-edge technology to help humanity search for its origins, seek evidence of life elsewhere, and see what lies beyond our planet.

Modern-day Juno is not a goddess; she's a robotic probe—and since July she has orbited Jupiter to peer beneath its clouds.

Juno is the latest is a series of NASA robotic missions that give us eyes and ears (and energetic particle detectors) in places humans have yet to venture.

In 2015, after nine years of spaceflight, the New Horizons probe reached icy Pluto, sending back first-ever close-ups of the dwarf planet with unanticipated insights. Among other results from the probe's instruments, we have gotten new clues to Pluto's very active geological life, with

NASA's Juno spacecraft arrived at Jupiter in July 2016, and began a mission to uncover the interior of the colorful, stormy planet.

glacial flows, volcano-like mounds, and a probable liquid ocean of ammonia-rich water beneath the frozen surface.

After its flyby of Pluto, the probe continued on into trans-Neptunian space. By May 2016, its Long Range Reconnaissance Imager had twice observed a Kuiper Belt object orbiting more than 3 billion miles from the sun, helping reveal new facts about this distant remnant of the early solar system.

New Horizons is following in the footsteps of Voyager 1 and 2, which launched in 1977 to explore Jupiter and Saturn. Four decades later, the twin spacecraft are further from Earth than anything ever built by human hands. In August 2012, Voyager 1 reached a new milestone, entering interstellar space, where the sun's influence ceases. Voyager 2 is not far behind: as of May 2016, Voyager 1 was more than 12 billion miles from Earth, and Voyager 2 was about 10 billion miles away.

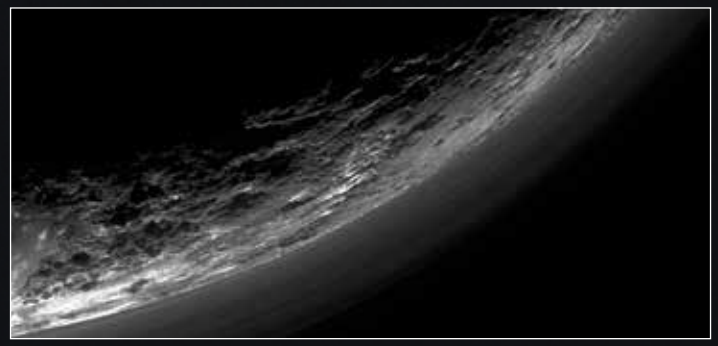
Space telescopes from Hubble and Kepler to the soon-to-launch James Webb look far beyond our solar system. Hubble has searched out stars and galaxies as they form, while Kepler has already identified thousands of planets—including more than two dozen found in their stars' "Goldilocks" zone where life as we know it could form and thrive.

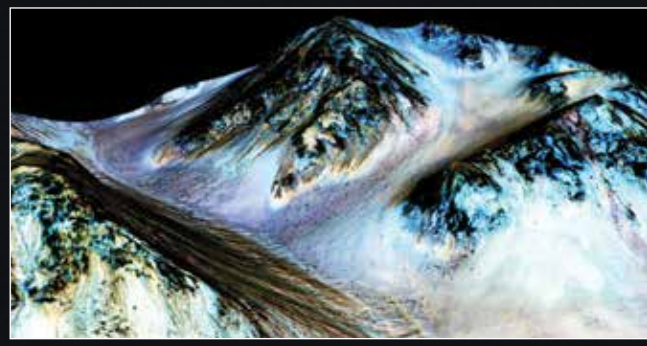
Some 20 years after Cassini launched to explore Saturn—and more than a decade after it helped bring the European Space Agency's-Huygens lander to Saturn's moon Titan—the probe continues to send back stunning images and scientific results. Huygens was the only landing ever accomplished in the outer solar system, and it sent back the first ground-level images ever seen from beyond the inner planets.

Closer to home, NASA has sent multiple probes to Mars, both into orbit and down to the surface. From MAVEN to Curiosity, Opportunity, and others, these missions from just the past decade and a half or so have significantly advanced our knowledge of our closest planetary neighbor, including finding evidence that liquid water still flows on the surface of the Red Planet.

These highlights touch on a mere handful of the decades of NASA's unmanned missions throughout our solar system and beyond—which, together, have led to hundreds of spinoffs on Earth in every sector of the economy and throughout our daily lives.

In addition to spinoffs you can find in this year's book (see pages 34, 82, 86, 126, 136, 144, and 168), the following are just a dozen of the most important robotics-related spinoffs from years past.

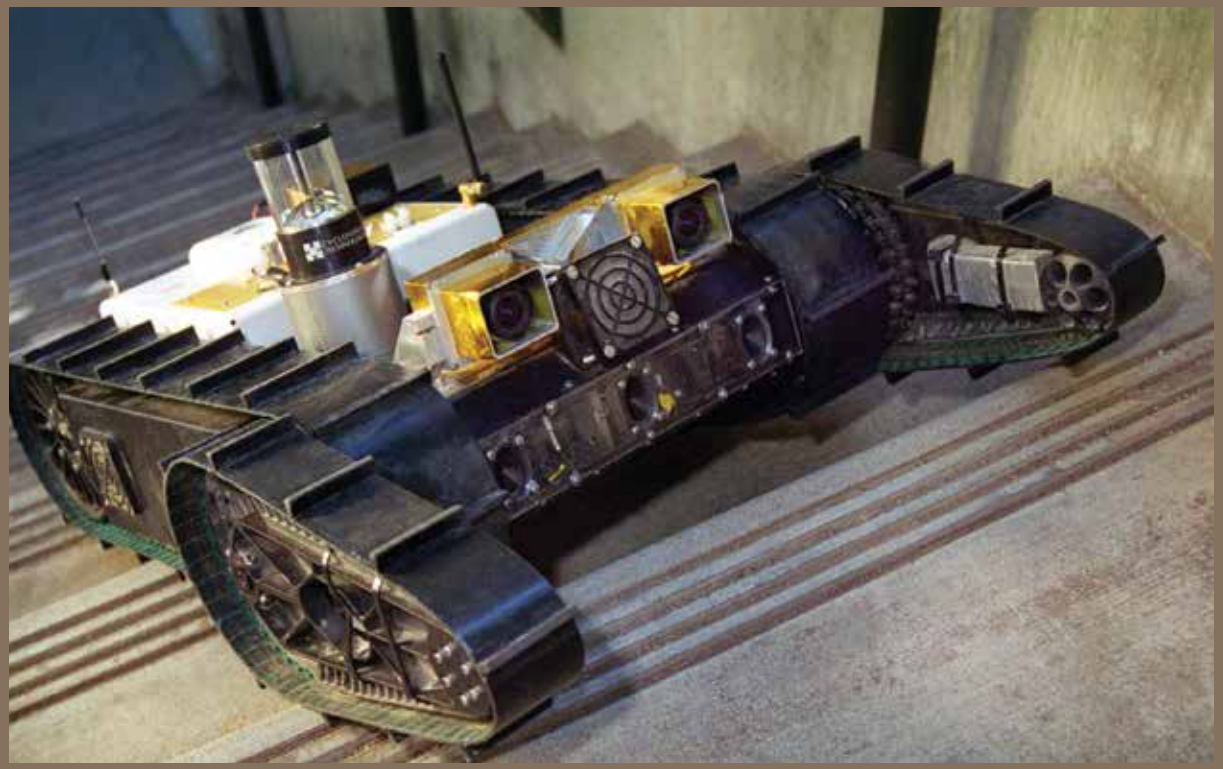




Some of NASA's stunning achievements through its robotics missions have included a decade of orbiting Saturn, a breathtaking flyby of Pluto, the discovery of liquid water flowing on Mars' surface today, and the detection of more than a thousand exoplanets orbiting other stars.

Braving Battlefronts to Save Lives

A number of employees at Burlington, Massachusetts iRobot Inc. drew from their NASA experiences—including the construction of a prototype Mars rover—to help develop the PackBot Tactile Mobile Robot, used by U.S. troops in Iraq and Afghanistan to help clear caves and bunkers, search buildings, and cross live anti-personnel minefields. PackBot provides soldiers with a safe first look so they know what to expect and how to respond. The robot can climb grades up to 60 percent and survive submersion in water up to 6.6 feet deep, and it possesses flippers that propel it up stairs, over curbs, and through daunting obstacles such as rocks, rubble, and debris. If PackBot flips over during operations, the robot can right itself within seconds.



Paving the Way for Hospital Robots

NASA's Jet Propulsion Laboratory provided funding for the Massachusetts Institute of Technology to develop capabilities for robots like Rocky 7, a NASA test rover that demonstrated navigation and sampling technologies useful on Mars. After developing the operating system, Daniel Theobald started working at Cambridge, Massachusetts-based Vecna Technologies. Today, Vecna's QC Bot incorporates systems based on the NASA work and is being used to ease logistics at hospitals. The technology has contributed to 20 new jobs at the company.

Breaking Olympic Records

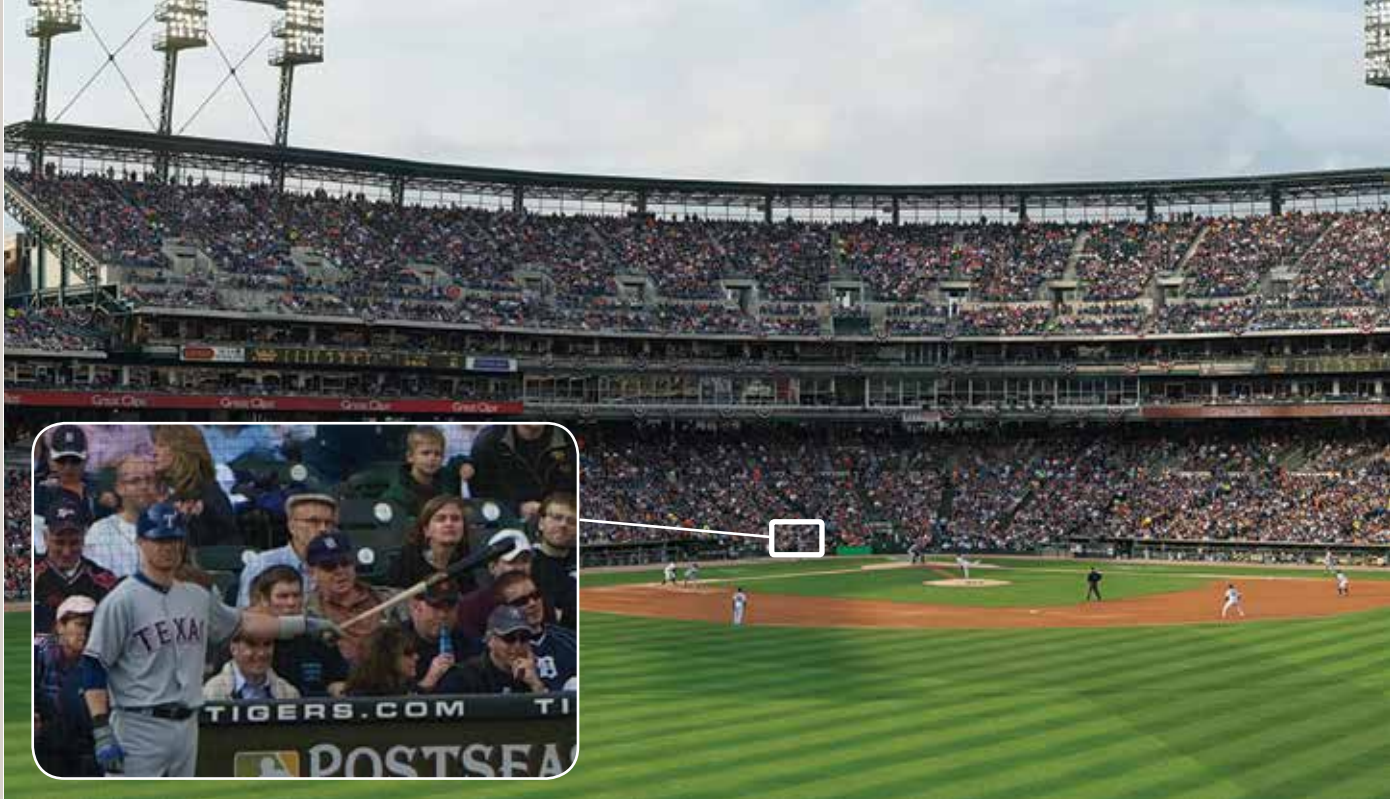
Inspired by principles used to create optics for the Hubble Space Telescope, the U.S. Olympic Committee worked with Goddard Space Flight Center to develop a new tool for sharpening speed skates. The skates sharpened using the new instrument demonstrated a marked improvement over conventionally sharpened ones, and the U.S. team used the polishing tool for the 2002 Salt Lake City Winter Olympics. At the event, Chris Witty raced her way to a gold medal in the 1,000-meter race, setting an Olympic and world record with her time.

Brewing a Better Cup of Coffee

During four summer internships at NASA Research Park, part of Ames Research Center, Matt Walliser learned various skills related to building intelligent, autonomous robotic systems. Some of these, like proportional-integral-derivative (PID) controllers and embedded communications, became central to the Blossom One coffee brewer created by San Francisco-based Blossom Coffee Inc., where Walliser is now chief engineer. The technology holds brew temperatures constant, ensuring consistent results, and allows the machine to brew according to recipes stored in the cloud.

Making Panoramic Photography a Snap

The Mars rover Panoramic Mast Assemblies inspired scientists at Ames and Carnegie Mellon University to find photographic and virtual exploration applications for consumers. Along with Austin, Texas-based Charmed Labs LLC, scientists created a prototype for the Gigapan robotic platform for consumer cameras, which automates the creation of highly detailed digital panoramas. The scientists also created a website and photographic stitching software to accompany the Gigapan platform. Among other places, the technology is now being used in baseball stadiums across the country: New York City-based Major League Baseball Advanced Media LP customized the Gigapan platform to accommodate in-game shots that capture nearly the whole stadium. Fans navigate the photos online and tag themselves and their friends using social media tools.

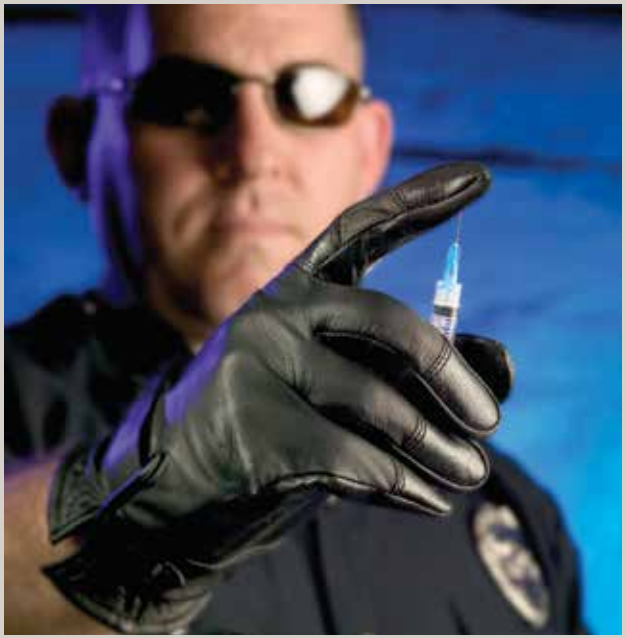


Boosting Optical Communication

Brooklyn, New York-based Amplification Technologies Inc. (ATI) employed SBIR funding from the Jet Propulsion Laboratory to improve its solid-state photomultiplier technology for interplanetary communication networks. ATI developed a small, energy-efficient, extremely high-gain sensor capable of detecting light down to single photons in the near-infrared wavelength range. The company has commercialized this technology in the form of its NIRDAPD photomultiplier, ideal for use in free space optical communications, lidar and ladar, night-vision goggles, and other light-sensing applications.

Protecting Public Safety Officers

In order to create mission-critical airbags in the 1990s, the Jet Propulsion Laboratory collaborated with New Ipswich, New Hampshire's Warwick Mills Inc. to weave multilayer textiles for both Pathfinder and the Mars Exploration Rovers. Warwick Mills applied techniques from the collaboration to its puncture- and impact-resistant TurtleSkin product line. The company's metal flex armor vests offer stab protection comparable with rigid steel plates, and its SoftPlate body armor offers protection from handgun bullets. International public safety and military customers are now benefiting from the TurtleSkin products.

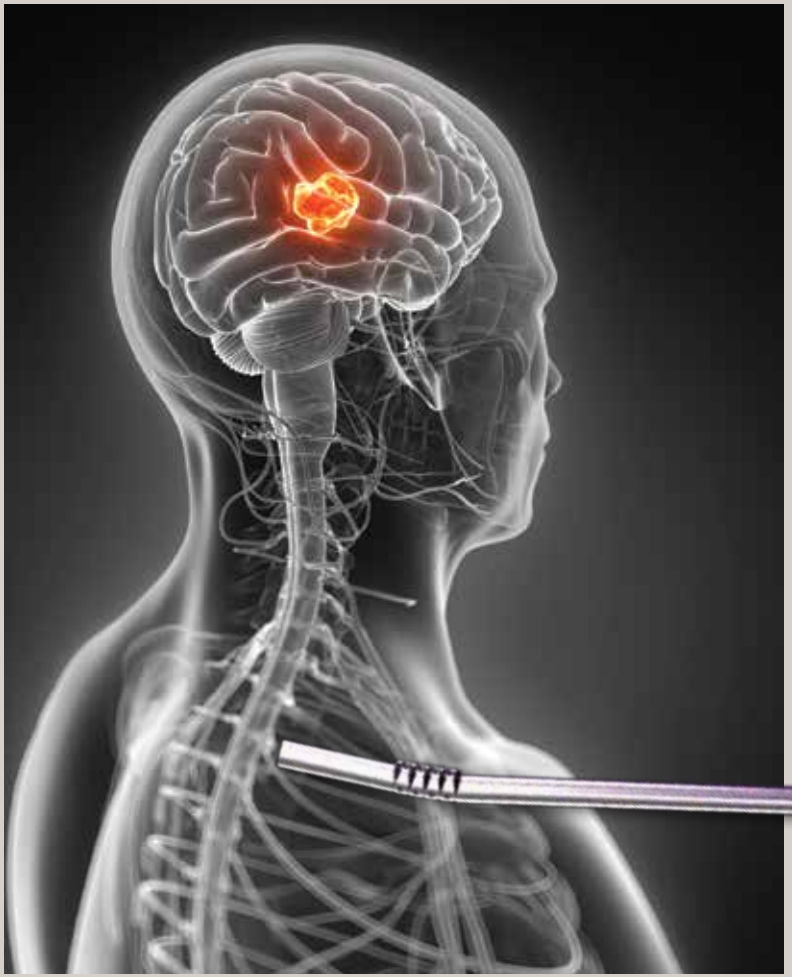


Lending a Hand in Warehouses

While building a robot to assist astronauts in space, Johnson Space Center worked with partners to develop robot reasoning and interaction technology. The partners created Robonaut 1, which led to Robonaut 2, and the work also led to patents now held by Universal Robotics in Nashville, Tennessee. The NASA-derived technology is being used in warehouses to allow robotic arms to see and learn with human-like flexibility, picking and sorting heavy items and packages.

Revolutionizing Brain Surgery

Using their expertise in designing small yet powerful tools for spacecraft and rovers, researchers at the Jet Propulsion Laboratory worked with the neurosurgeon who directs the Skull Base Institute in Los Angeles to create the first endoscope fit for brain surgery and capable of producing 3D video images. It is also the first to be able to steer its lens back and forth. These improvements to visibility are expected to improve safety, speeding patient recovery and reducing medical costs.



Scanning Groceries and Parcels

In preparation for a repair mission for the Hubble Space Telescope, which was launched with a misshapen mirror, Goddard Space Flight Center issued a call for optics companies to accurately measure replacement parts. AOA Xinetics, now a division of Northrop Grumman Corporation based in Cambridge, Massachusetts, created a tool to detect mirror defects, which it has incorporated into a commercial 3D imaging system. Among its applications is a package-detection device, now used by all major shipping companies, and a self-checkout grocery scanner in stores around the country.

Smoothing the Way for Commercial Space

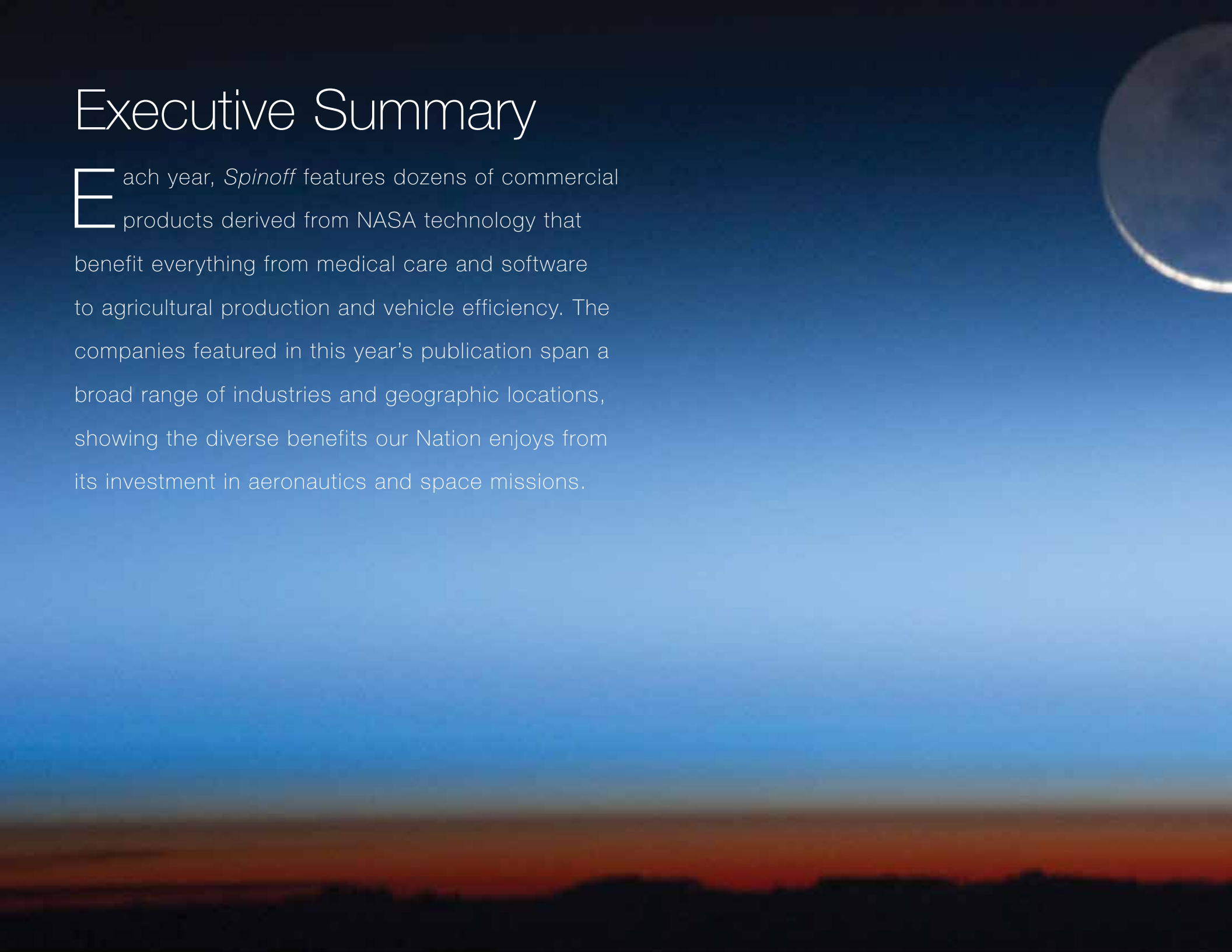
Tungsten disulfide is a dry lubricant developed for the Mariner space probes managed by the Jet Propulsion Laboratory in the 1960s and '70s. Applied Tungstenite, a company based in Temecula, California, offers impinging services that utilize the material and has found a client base in the burgeoning commercial space industry, as well as among manufacturers that make engine parts for racecars.

Targeting Digital Marketing

Thousand Oaks, California startup Beyond Limits Corporation licensed an artificial intelligence program and language-understanding software from the Jet Propulsion Laboratory in 2013 and retooled the programs to target online advertising. Rather than simply remembering that a user once bought something from a particular website or pushing content based on words a user has typed, the software seeks to understand a person's intent and sentiment at a given time and use that data to push relevant content. ❖

Executive Summary

Each year, *Spinoff* features dozens of commercial products derived from NASA technology that benefit everything from medical care and software to agricultural production and vehicle efficiency. The companies featured in this year's publication span a broad range of industries and geographic locations, showing the diverse benefits our Nation enjoys from its investment in aeronautics and space missions.



Executive Summary

Health and Medicine

(34) **Active Pixel Sensors Lead Dental Imagery into the Digital Age**

Complementary metal oxide semiconductor (CMOS) image sensors invented at the Jet Propulsion Laboratory have taken over the digital imaging industry, but one of their earliest applications was in dental radiology. When the technology was new, Long Island City, New York-based Schick Technologies, now part of Sirona Dental, obtained an exclusive license to use it for dental imagery, which it still retains. CMOS allows for much more energy-efficient X-ray imagers than were possible with previous digital imaging technology.

(38) **Mini Heat Pipes Wick Away Heat in Brain Surgery**

Over the course of more than 40 SBIR contracts since the 1980s, many at Glenn Research Center, NASA has helped Lancaster, Pennsylvania-based Thermacore advance the technology of heat pipes, a tool used to move heat so it can dissipate safely. In the last decade or so, the NASA-improved heat pipes have been adapted to medical uses, including in bipolar forceps used in brain surgery.

(40) **Fluorescent Diagnostic Test Readers Offer Fast, Low-Cost Results**

Ames Research Center wanted a simple, lightweight device to diagnose astronauts' illnesses within minutes. Los Angeles-based Holomic, now Cellmic LLC, was hired as a subcontractor to develop a device that used a smartphone to read results from a lateral flow test strip—the same technology as a home pregnancy test—with ultraviolet light. The company had made similar devices using visible light. Cellmic markets its resulting HRDR-300 Fluorescent Immunoassay Reader to companies that develop their own tests.

(42) **Cooling Garments Find New Medical, Athletic, and Industrial Uses**

In the 1960s and '70s, Bill Elkins worked with engineers at NASA and the Air Force, including several at Ames Research Center, on liquid cooling garments to be worn under spacesuits and flight suits. He has spun that experience off into several companies, including Downers Grove, Illinois-based WElkins LLC. The company markets varieties of the cooling technology to prevent brain damage after heart attacks or strokes, improve sports performance, treat concussions, and keep workers from overheating under heavy protective gear.

(46) **Space-Based Bone Scanner Expands Medical Research**

As a part of an effort to upgrade ISS research facilities managed by Johnson Space Center, the Center for the Advancement of Science in Space (CASIS) worked with Techshot Inc. to build a bone densitometer suitable for use in space. The Greenville, Indiana-based company's product, dubbed Bone D, is operating commercially on the station for a number of clients looking to take advantage of studies performed in microgravity.

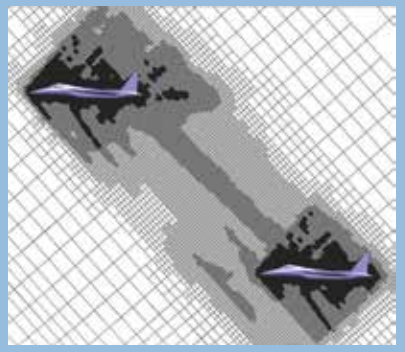
(48) **Temperature-Regulating Fabrics Keep Babies Comfortable**

One method Johnson Space Center investigated for managing heat inside a spacesuit was the use of phase-change materials (PCMs). Like ice cubes in a drink, PCMs absorb heat as they change from solid to liquid, and, if exposed to colder temperatures, they release that heat as they refreeze. An SBIR contract led to the creation of fabrics incorporating PCMs, most recently commercialized by San Fransicso-based Embrace Innovations in wraps and blankets that help keep babies at an optimal temperature.

Transportation

(52) Reconfigurable Radio Tracks Flights Worldwide

NASA was looking for a new high-bandwidth, software-reconfigurable radio. Through a 50/50 cost-share cooperative agreement, Glenn Research Center developed one with Harris Corporation, and the final product flew in the ISS SCaN Testbed and was honored with an R&D 100 Award. The Palm Bay, Florida-based company used what it built to create its AppSTAR radio, which soon will be tracking airplanes worldwide.



(56) Design Software Shapes Future Sonic Booms

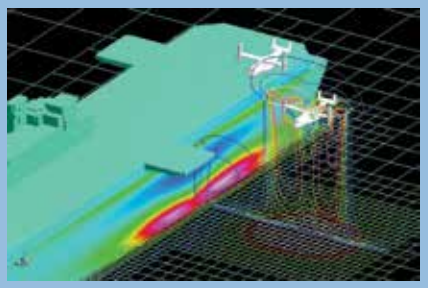
Computational fluid dynamics (CFD) was hailed as a way to replace costly wind tunnel testing, but the software was time-consuming and itself costly to implement. Michael Aftosmis at Ames Research Center came up with a way to simplify and automate CFD processes. Desktop Aeronautics, now owned by Reno, Nevada-based Aerion Corporation, acquired the commercial license and added features to make it more user-friendly, and they have clients among universities, Government contractors, and commercial aerospace companies.

(58) Orion Parachute Innovations Carry Commercial Rockets Back to Earth

Airborne Systems Inc., whose Space and Recovery Systems branch is in Santa Ana, California, worked as a subcontractor to build the parachute system for the Orion capsule. The design is based in part on the Apollo spacecraft's parachutes but incorporates updates and improvements requested by Johnson Space Center, which managed the contract. Johnson also carried out costly, repeated drop tests to prove the parachutes, which Airborne Systems now sells to several commercial spacecraft companies.

(60) CO_2 Sensors Monitor Vehicle Emissions from Above

Through the ASCENDS project, NASA hopes to learn more about how carbon dioxide (CO_2) seasonally concentrates and dissipates in the atmosphere. A contractor from Langley Research Center who worked on the project went on to found Knoxville, Tennessee-based Hager Environmental and Atmospheric Technologies (HEAT) Inc. HEAT's first product, based on a NASA sensor designed to measure atmospheric CO_2 from space, remotely measures car and truck emissions and is currently used by four U.S. states to check vehicle compliance.



(62) Software Opens Computational Fluid Dynamics to the Uninitiated

Following a 1999 SBIR contract with Ames Research Center, Sukra Helitek Inc. released its Rot3DC program to model air flows generated by aircraft rotors. A series of additional NASA and military SBIR contracts for the Ames, Iowa-based company, including seven more from Ames, has resulted in RotCFD—short for rotor computational fluid dynamics. The software simplifies the esoteric and time-consuming work of modeling how rotorcraft designs would move the air around them, opening the field of CFD to students and NASA engineers alike.

(64) Hydraulic Carts Streamline Structural Tests for Aircraft

Aircraft hydraulic testing facilities can be jungles of hoses, wires, and pipes. When replacing its hydraulic system, the Flight Loads Laboratory at Armstrong Flight Research Center significantly reduced the miles of connections by hiring East Aurora, New York-based Moog Inc. to develop a series of hydraulic carts. Each SmartCART can connect eight hydraulic actuators to a front-end computer with just two connections. The system is especially useful for facilities that have to reconfigure test setups frequently.

Public Safety

(68) Orion Video Requirement Advances High-Speed, Compact Cameras

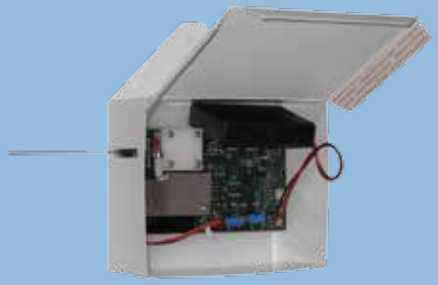
To film parachute deployment on the Orion spacecraft, Johnson Space Center required a high-speed, compact, rugged video camera. Integrated Design Tools (IDT) of Pasadena, California, which specializes in cameras for industrial and scientific markets, such as crash testing, was subcontracted. IDT developed a camera capable of filming up to 1,000 frames per second and backing that data up nearly as fast. All of IDT's Os series of cameras now include the high-speed, solid-state memory developed for Orion.

(72) **Rocket Technology Stops Shaking in Its Tracks**

In testing, the Ares I launch vehicle displayed a serious vibration problem—shaking that resonated dangerously, causing potentially hazardous conditions in the crew capsule right above the booster. Engineers at Marshall Space Flight Center found a solution, creating a brand new, low-cost, lightweight damper that could become the industry standard for buildings, bridges, and many other structures that vibrate or shake. New York City-based Thornton Tomasetti markets the technology to make buildings safer against the wind and from earthquakes.

(76) **Micromachined Sensors Monitor Train Rails, Predict Failures**

Ridgetop Group of Tucson, Arizona, created its RotoSense rotational vibration sensor under SBIR contracts with Glenn Research Center, intending it to be installed on gears in helicopter transmissions to monitor their condition. To create its new Railsafe system, Ridgetop repackaged the sensors to sit on train axles and retooled its algorithms to identify anomalies in rails. The company tested Railsafe and launched it in 2015. Next, Ridgetop will enable it to predict failures in rails and wheels.



(78) **Wire Sensors Alert to Dangerous Conditions in the Clouds**

Under two SBIR contracts with Glenn Research Center, Anasphere Inc. designed a vibrating wire sensor that can give scientists information on how much supercooled liquid water is lurking in the skies. The inexpensive, lightweight sensor is helping NASA develop a ground-based system to warn of dangerous icing conditions for airplanes. The Bozeman, Montana-based company is also selling it to others, including the Department of Energy and the Chinese affiliate of German radiosonde company GRAW.

(80) **Fast-Flow Nanofiber Filters Purify Water at Home and in the Field**

Tom Smokoff, founder of Water Pure Technologies Inc. in Murray, Utah, wanted to build low-cost water filtration systems fast enough to efficiently supply whole villages. He found the NanoCeram filter, originally developed for Johnson Space Center, which quickly eliminates better than 99.9 percent of viruses and bacteria. Smokoff buys the NASA-created filters from a licensed manufacturer and now sells portable, battery-operated or hand-cranked systems that can be packed up and brought to a water source.

(82) **Miniaturized Vacuum Pumps Play Big Roles on Mars and Earth**

One of Curiosity's tools is a mass spectrometer used to analyze rock and gas samples on the Red Planet. Through a series of SBIR contracts with the Jet Propulsion Laboratory, Creare Inc., based in Hanover, New Hampshire, built the vacuum chamber for the spectrometer by heavily modifying existing technology. The company has since commercialized its smaller, more rugged vacuum pumps for Earth-based applications, including mining operations, chemical-weapon and bomb detectors, and more.

Consumer Goods

(86) **CMOS Sensors Enable Phone Cameras, HD Video**

In the 1990s, Jet Propulsion Laboratory engineer Eric Fossum invented what would become NASA's most ubiquitous spinoff—digital image sensors based on complementary metal oxide semiconductors (CMOS). These were significantly smaller and more efficient than the charge-coupled-device imagers of the day and eventually enabled tiny, battery-friendly cell phone cameras, high-definition video cameras—such as those offered by San Mateo, California-based GoPro—and social media as we know it. By 2015, the CMOS market reached nearly $10 billion.

(90) **Novel Threading Enables New Approach to Golf Clubs**

A researcher at Goddard Space Flight Center came across Spiralock threading, a 1979 invention that increased the clamping power of screws and bolts, enabling them to survive repeated Shuttle launches. He tested it extensively and published the results, after which a variety of industries adopted the technology. Most recently, it let Carlsbad, California-based Cobra Puma Golf put a "spaceport" in the head of its new driver, which allowed for the lowest center of gravity ever achieved in a golf club.

(94) **Blue-Light-Cancelling Lens Gives Skiers a Clearer View**

In the 1990s, a scientist at Ames Research Center developed optical filters to block blue and green light, allowing other hues to stand out and making camouflaged objects more visible in forests. His work was later commercialized through a Space Act Agreement with NASTEK, which then partnered with Wheatridge, Colorado-based Optic Nerve Inc. to create a line of ski goggles that filter about 95 percent of blue light, giving professional and amateur skiers alike a clear view on the slopes.

(96) **Rechargeable Hearing Aid Batteries Draw from NASA Research**

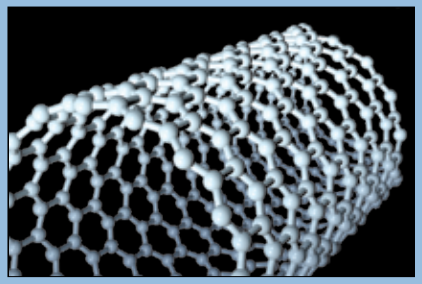
In its early days, NASA spent much effort developing rechargeable silver-zinc batteries, as the pairing offers a higher power-to-weight ratio than any other battery couple. Significant advances in the batteries' durability were made at Glenn Research Center, which ZPower of Camarillo, California, used as part of its starting point, undertaking years of additional development before releasing its rechargeable hearing aid batteries, the first that can last all day on a single charge.

(100) **Large-Scale 3D Printer Brings Manufacturing to the Masses**

A team of former Johnson Space Center employees founded re:3D in Houston, Texas with a vision to bring additive manufacturing power to the developing world. Drawing on skills they honed at NASA, the team built an inexpensive printer 30 times larger than competing desktop models. They have customers worldwide, including right at NASA, but they continue to work toward their development mission by donating one for every hundred printers sold.

(104) **Professional Development Program Gets Bird's-Eye View of Wineries**

As a part of Langley Research Center's DEVELOP Program—in which students and young professionals from across the country get opportunities to work in the fields of science, technology, engineering, and mathematics—NASA used satellite imagery to map vineyards across Virginia in unprecedented detail. State officials are using the maps to encourage an expansion in local wineries and may also use NASA data in the future to map pesticide use and monitor crop health.



(106) **Carbon Nanotube Resin Shores Up Boats, Bikes**

Carbon nanotubes offer 100 times the strength of steel at just one-sixth the weight. The potential for space applications seemed huge, but the material was challenging to work with, so NASA awarded SBIR funding to Zyvex Technologies, based in Columbus, Ohio. That was instrumental in helping move forward the early research needed to help the company put it to use in commercial products from sporting goods to ships.

Energy and Environment

(110) **GPS Correction Technology Lets Tractors Drive Themselves**

With a license for software created by the Jet Propulsion Laboratory (JPL) to stream corrected GPS data and a contract to receive data from JPL's global network of reference stations, Moline, Illinois-based John Deere released StarFire receivers that let tractors drive themselves, were affordable, didn't require a local radio tower, and could be used all over the world. Automated guidance reduces the time and resources needed to care for fields and increases crop yield and quality.

(112) **Controlled-Release Fertilizer Takes Root in Fields, Groves Worldwide**

Fertilizer helps crops grow better, but nutrient runoff can lead to serious environmental problems. Ed Rosenthal, founder of Sarasota, Florida-based Florikan, had an idea to control the nutrient release to avoid runoff and maximize the benefit to the plant. He perfected the formula thanks to 40 hours of NASA consulting, and the fertilizer is now sold around the world—and also used on the ISS for project Veggie.

(116) **Satellite Imagery Sheds Light on Agricultural Water Use**

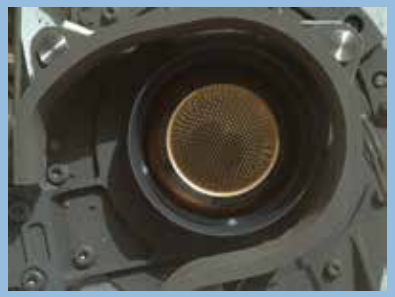
Keeping track of how water gets used across millions of acres of crop land is no simple task. Researchers created a program called EEFlux to make it easier. It works with Earth Engine from Mountain View, California-based Google to quickly map evaporation and transpiration, based on infrared images captured by Landsat's Earth-observing satellites, and is already used by the California Department of Water Resources, the California Water Control Board, and the World Bank.

(118) **Building Sensor Monitors Power Usage, Device by Device**

Verdigris Technologies Inc. created a sensor that "listens" to electronic signals as they pass through a circuit panel to determine how much power each device is using. Thanks to a nonreimbursable Space Act Agreement and testing at Ames Research Center's Sustainability Base, the Moffett Field, California-based company was able to bring its product to market and has found happy customers in hotels, hospitals, corporate offices and more.

(122) **Earth Observation Spots, Helps Prevent Rainforest Fires**

A partnership between NASA and Arlington, Virginia-based Conservation International let the company use funding from the Agency's headquarters and the supercomputing power of the NASA Earth Exchange at Ames Research Center to upgrade, combine, and expand its fire alert and fire risk forecasting systems to create Firecast. The system lets authorities and conservationists in developing countries spot rainforest wildfires, including illegal burns, and limit legal burning activities to times when fire risks are low.

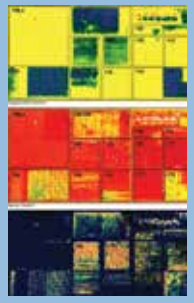


(126) **Mineral Analyzer Shakes Answers Out of Soil and Rocks**

A small, rugged X-ray diffraction (XRD) tool, CheMin, went to Mars on the Curiosity rover, and one of its inventors, Philippe Sarrazin, started a company to sell devices based on the same technology. The final product incorporated SBIR-financed work as well as a license for a patent filed while Sarrazin worked at Ames Research Center. Now Olympus Scientific Solutions America, based in Waltham, Massachusetts, sells the XRD devices to mining and drug companies as well as Government drug watchdogs.

(130) **Low-Cost Flow Meters Bring Efficiency, Reliability to Nuclear Plants**

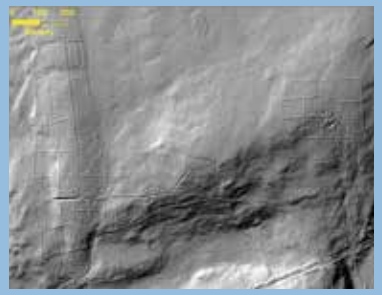
Innovators at Marshall Space Flight Center co-invented a deceptively simple device to measure the flow of liquid oxygen into rocket engines. The so-called balanced flow meter was then commercialized in industrial applications where it has saved millions, if not billions, of dollars in costs. Most recently, Graftel LLC of Elk Grove Village, Illinois, has brought the inexpensive device to the nuclear industry, where it has dramatically increased flow-measurement accuracy, reduced noise, increased safety, and saved on operation costs.



(132) **Computer Learning Program Inventories Farmers' Fields**

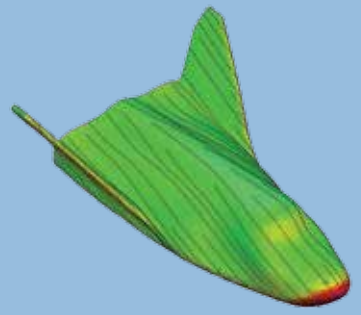
Under a 2014 SBIR contract with Goddard Space Flight Center, GeoVisual Analytics of Boulder, Colorado, improved techniques for using satellite imagery to classify land and assess vegetation indexes. The work spawned the Computer Learning Imagery Platform (CLIP), now used with drone images to assess the types, stages of growth, and health of crops in fields for Taylor Farms, the product's first customer and the world's largest fresh-cut vegetable producer. This allows Taylor Farms to predict annual yields.

Information Technology



(136) **Laser Imaging Helps Archaeologists Dig Up History**

Archaeologists are using tools developed for space missions, like remote scanning with lasers, or lidar, to help search for clues to long-ago history. One company making the scanners is Teledyne Optech, a Canadian company with offices in Henrietta, New York, which most recently designed a lidar instrument for the OSIRIS-REx asteroid return mission managed at Goddard Space Flight Center, and which has incorporated space mission innovations into their commercial offerings.



(140) **Program Predicts Aerothermodynamics of Reentry, Subsonic Flight**

An engineer at Ames Research Center created software called Configuration-Based Aerodynamics (CBAERO), capable of importing spacecraft models created with computer-aided design and predicting the aerodynamic and aerothermodynamic forces they would experience during reentry. The program generates results with nearly the accuracy of traditional computational fluid dynamics in far less time. Through software usage agreements, more than 20 businesses, including Dulles, Virginia-based Orbital ATK, and several Department of Defense agencies and universities use CBAERO.

(142) **Data Acquisition System Captures Machine Performance**

Under contract with Kennedy Space Center, Wakefield, Rhode Island-based Dewetron delivered a powerful system to monitor performance on the Space Launch System mobile launch platform. The easy-to-use system captures data with one universal signal conditioner—allowing easy analysis across multiple signals—and is now a popular part of Dewetron's product line. Updated versions have sold to aerospace companies and car companies from Ford to BMW, as well as many other industries.

(144) **Light-Analysis Software Explodes across Industries**

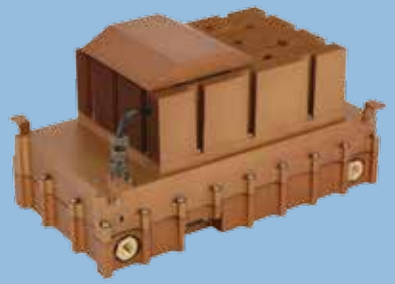
Under two SBIR contracts with the Jet Propulsion Laboratory, Lambda Research Corporation of Littleton, Massachusetts, developed its TracePro light ray-tracing software in the mid-1990s to help engineers predict stray light in imagers. Since then, the program—the first of its kind compatible with computer-aided design software—has found uses in industries as diverse as overhead lighting, light pipes for electronics, solar collection, noninvasive health-monitoring, laser surgical devices, car dashboard displays, optics for missile systems, and more.

(148) **Connectors Link Data Networks for Orion, Industry**

The Orion crew capsule may resemble its Apollo ancestor on the surface, but its internal systems reflect nearly half a century of development. Among these is a 21st-century data system capable of quickly transmitting massive amounts of data, overseen by Johnson Space Center and designed by Smiths Connectors, based in Costa Mesa, California. The company has commercialized data connectors it designed for NASA in other demanding applications, such as in the aviation and oil and gas exploration markets.

(150) **Scheduling Software Plans Public, Private Space Missions**

Alex and Ella Herz learned about space mission scheduling while working payload operations at Johnson Space Center, and Alex and Doug George later created scheduling software for a planned lidar mission at Goddard Space Flight Center. The three founded Greenbelt, Maryland-based Orbit Logic, where one of their first products was STK Scheduler, a generic, reconfigurable scheduling program for space operations. Orbit Logic has sold licenses for the program to around 250 customers, including most NASA field centers.



(152) **Power Amplifiers Boost Radar, Communications, Defense Systems**

As a subcontractor under an SBIR contract from the Jet Propulsion Laboratory, QuinStar Technology Inc. of Torrance, California, developed a solid-state power amplifier of unprecedented efficiency. While most comparable devices lose 20 percent of their amplified energy when their signals recombine, QuinStar's lose 8 percent. The solid-state technology requires lower voltage and is lighter, more compact, and more reliable than its tube-based predecessors, making it ideal for radars, communications equipment on spacecraft, and unmanned aerial vehicles.

(156) **3D Weaving Technology Strengthens Spacecraft, Race Cars**

Seeking a new, structurally strong heat shielding material, Ames Research Center teamed up with high-tech 3D weaving company Bally Ribbon Mills. With seed money from Ames, they created a material that solved a challenging connection issue on the Orion's heat shield. Development continued with additional funding in part through SBIR contracts, and now the Bally, Pennsylvania-based company sells the material to aerospace companies, and uses the techniques to make larger, denser blocks of 3D carbon composites for race cars.

(160) **Vibration Tables Shake Up Aerospace, Car Testing**

Team Corporation has been building vibration-testing equipment for NASA since the 1950s. Most recently, the Burlington, Washington-based company built a high-powered system to test the James Webb Space Telescope at Goddard Space Flight Center. Innovations the company has made to satisfy the Agency's requirements over the years have been used in their commercial products for testing nuclear warheads, cars, and many other items.

(162) **Astronauts Instruct Newcomers on Peculiarities of Spaceflight**

The growing numbers of engineers, managers, and others in the space industry generally do not graduate with much knowledge of the unique challenges posed by space travel. The International Flight Test Institute in Mojave, California, aims to fill that knowledge gap with crash courses in spaceflight taught in part by two former astronauts. Largely based on the training they received at Johnson Space Center, the curriculum includes everything from orbital mechanics to space law.

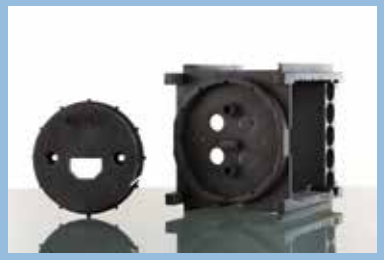
(164) **Polyimide Aerogels Boost Antennas, Insulate Pipes**

Glenn Research Center's Mary Ann Meador is an expert in aerogels: low-density solids that make excellent insulators. Using polyimide polymers, she and her team created a new aerogel five times stronger than earlier polymer-reinforced silica aerogels and one that can be cast into a thin, very flexible layer. FLEXcon, in Spencer, Massachusetts, licensed the patent in 2015 and is selling the aerogel as insulation for pipes in extreme environments, among other applications.

(166) **Privately Built Facility Offers Advantages in Space Exposure Testing**
NASA's Materials International Space Station Experiment (MISSE) series tests the effects of exposure to space on various materials, housing them outside the ISS. Under cooperative agreements with Johnson Space Center, Houston-based Alpha Space is designing the next MISSE facility to provide advantages over previous versions at lower costs. Space not reserved for NASA on the new facility, scheduled for launch in 2017, will be available for purchase by companies, universities, and Government agencies.

(168) **Optical Filters for NASA Imagers Focus on Cutting Edge**
For a mission to upgrade the Hubble Space Telescope, Goddard Space Flight Center selected optical filters manufactured by Materion Corporation, based in Westford, Massachusetts. The project stretched the company's expertise and capabilities and has led to a range of improved products and new devices that are matching paint in hardware stores and depositing thin coatings in industrial settings, among other applications.

(170) **Zinc-Silicate Coating Blocks Corrosion**
NASA chemists designed an anti-corrosion coating for metals and used it to protect launch structures at Kennedy Space Center from the tropical air as well as the temperature spikes of a rocket launch. Polymer manufacturer Polyset, of Mechanicville, New York, helped the original license holder for the coating make a key ingredient in the 1980s and is now producing the coating itself, for use in bridges, hydroelectric facilities, rail cars, and oil rigs.



(172) **Outgassing Test Facility Brings New Materials into Space Industry**
In 2013, the Goddard Space Flight Center Outgassing Laboratory tested four varieties of Windform fiber-reinforced polyimides for their manufacturer, CRP USA, headquartered in Mooresville, North Carolina. The lab found that the materials, which are used for 3D printing, met NASA's standards for low outgassing. As a result, the company entered the space business, where it has found around a dozen clients. High strength and temperature resistance are among the materials' advantages for space applications.

(174) **Shuttle, Hubble Work Lead to Strength in Custom Current Sensors**
Subcontracts to provide current and voltage sensors first for the Space Shuttle at Johnson Space Center and then for the Hubble Space Telescope at Marshall Space Flight Center led American Aerospace Controls to develop the ability to create, test, and document highly reliable, customized components. Having started out making standardized parts, the Farmingdale, New York-based company leveraged these capabilities to cultivate a broad, international customer base for specially tailored, space-grade transducers.

(176) **High-Heat Cement Gives Ashes New Life**
Stennis Space Center engineers are always on the lookout for materials that can hold up better in the inferno of a rocket test. A Louisiana Tech University team had a good candidate: geopolymer concrete made with fly ash left over after burning coal. Testing under a dual-use cooperative agreement confirmed the material's strong resistance to heat and corrosion, prompting the Louisiana Tech team to start Ruston, Louisiana-based Alchemy Geopolymer Solutions LLC, to help turn waste ash into concrete across the country.

15 companies in this book developed their commercial products with NASA SBIR funding

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NASA Spinoff Technology across the Nation

Health and Medicine

1. Active Pixel Sensors Lead Dental Imagery into the Digital Age (NY)
2. Mini Heat Pipes Wick Away Heat in Brain Surgery (PA)
3. Fluorescent Diagnostic Test Readers Offer Fast, Low-Cost Results (CA)
4. Cooling Garments Find New Medical, Athletic, and Industrial Uses (IL)
5. Space-Based Bone Scanner Expands Medical Research (IN)
6. Temperature-Regulating Fabrics Keep Babies Comfortable (CA)

Transportation

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8. Design Software Shapes Future Sonic Booms (NV)
9. Orion Parachute Innovations Carry Commercial Rockets Back to Earth (CA)
10. CO_2 Sensors Monitor Vehicle Emissions from Above (TN)
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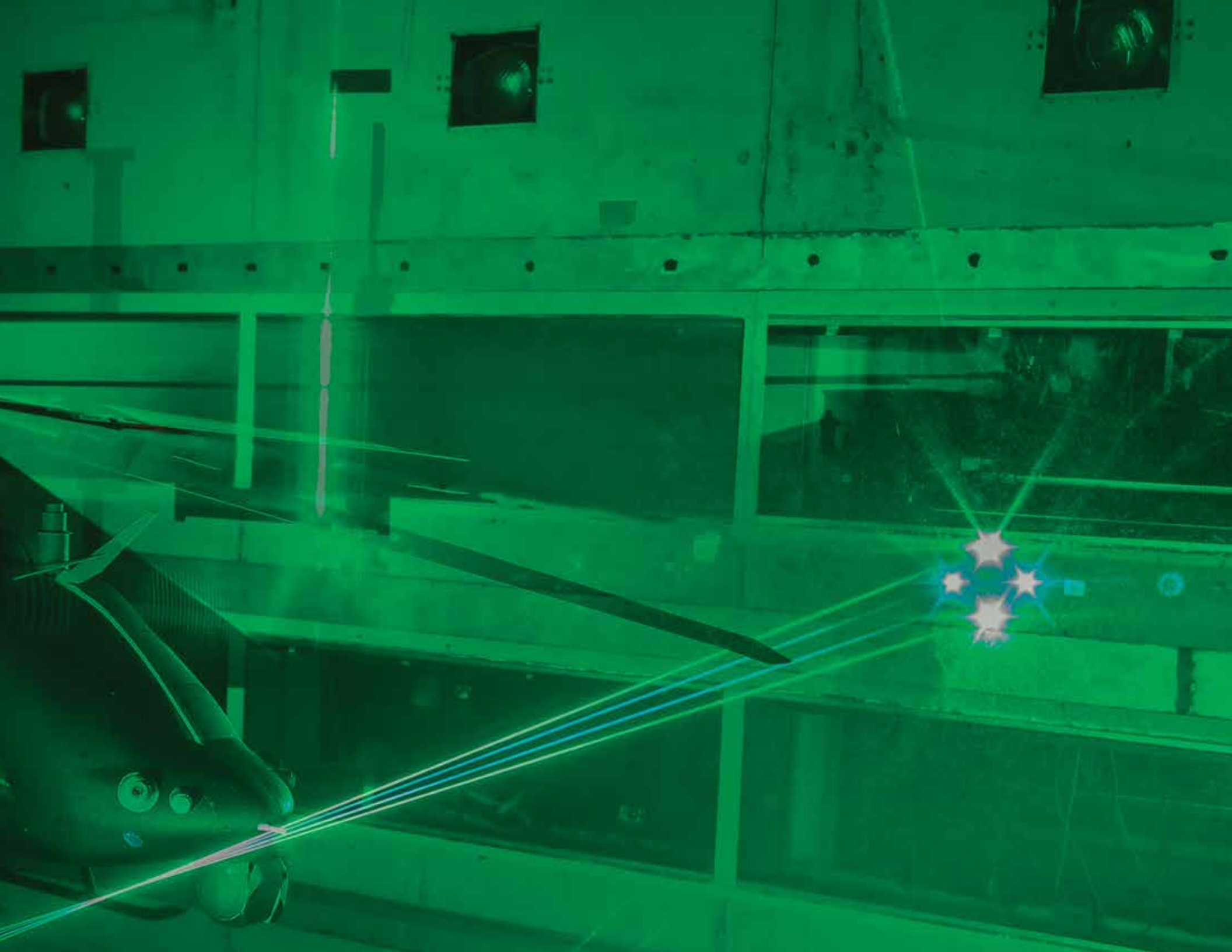
This map details the geographic location of each company that appears in *Spinoff* 2017.

NASA Technologies Benefiting Society

There's more space in your life than you think: NASA research and development has tangible benefits that go beyond supporting mission needs. Spinoffs create jobs, generate revenue, and save costs for businesses. They even save lives. Through new medical devices, agricultural products, innovative consumer goods, and more, NASA technology works for the benefit of the Nation and the world.



Health and Medicine

From tools for brain surgery to dental X-rays, NASA research yields technologies that enhance medical treatments and save lives. In this section you can learn—among other things—how fabrics, cooling suits, and diagnostic tests designed for astronauts have led to new medical products for infants, injured athletes, and those most at risk for sudden epidemics.

Active Pixel Sensors Lead Dental Imagery into the Digital Age

NASA Technology

They're in your cell phone camera and probably in your handheld digital camera, but they may have been in your dentist's X-ray machine first: image sensors based on CMOS technology. And they got their start at NASA.

NASA has an interest in capturing all sorts of images, in the visible spectrum and beyond. One of the pursuits the Agency is most famous for is transmitting spectacular vistas of other worlds, distant galaxies, and our home planet. Aside from providing windows into the cosmos, these images have significant scientific value, as they can be analyzed, for example, to determine the composition and temperatures of the objects they depict.

NASA spent much of the 1980s developing image sensors based on charge coupled device (CCD) technology, which had enabled the first digital cameras. But in the early 1990s, under a new administrator, NASA adopted a "faster, better, cheaper" approach, and engineer Eric Fossum, who had recently joined the Agency's Jet Propulsion Laboratory (JPL), had an idea that might achieve that goal for spaceborne imagers.

CCD-based pixel arrays operate like a bucket brigade, with the light-generated charge from each pixel passing along the entire array of pixels to the corner of the chip, where it is amplified and recorded. Fossum thought such imagers might be supplanted by CMOS—or complementary metal oxide semiconductor—technology, which consists of microelectronic transistors that have been integral to computer circuitry since the 1960s. Being amplifiers in and of themselves, photosensitive CMOS pixels in an array could each amplify their own signals. The concept had been explored before and discarded, but technology had advanced considerably in the ensuing decades.

The use of CMOS imagers in dental X-ray devices reduces susceptibility to electrical noise and gives dentists images they can manipulate to make more accurate diagnoses.

In Fossum's innovation, pixels also contained a mini-CCD to transfer charges internally, as well as an amplifier that reduced readout noise compared to the earlier CMOS image sensors. By using well-established CMOS manufacturing processes to make an array of photodetectors, Fossum and his team were able to integrate almost all the other camera electronics, such as timing and control systems, an analog-to-digital converter, and signal processors, onto a single chip. The "camera on a chip" was born, and it would enable much smaller, more efficient imaging devices (*Spinoff* 1999, 2002, 2010; see also page 86).

The term active pixel sensor (APS) entered the popular lexicon. "Active pixel means the pixel's got an active transistor in it, an amplifier," says Fossum.

But the budding technology required a lot of development, and it was not immediately embraced. "Displacing an incumbent technology is always a big challenge," Fossum says. "The new technology must have compelling advantages."

Technology Transfer

In the interest of advancing and commercializing CMOS-APS, JPL entered into several Technology Cooperation Agreements (TCA) with industry partners during the early 1990s. No funds were exchanged under these agreements, but JPL and partners shared resources, expertise, and equipment, working together to advance and apply the new camera-on-a-chip technology.

Major players, including Kodak and AT&T Bell Labs, established such agreements with JPL and explored commercial uses for CMOS-APS, but many of these early efforts stalled for lack of corporate follow-through. In the end, perhaps the most significant TCA began when David Schick of Schick Technologies, then a three-person outfit in Long Island City, New York, contacted Fossum in 1994.

"I was trying to tell him it was still an early technology. I couldn't make small pixels," Fossum recalls. "He didn't care."

"As a dental device manufacturer, we were looking at next-generation technology specific to dental imagery, and specifically, radiology," says Stan Mandelkern, vice president of engineering at the original New York headquarters for Schick, which became a subsidiary of Sirona Dental Systems in 2006.

The company had already developed CCD-based digital imagers to replace traditional X-ray film. Their higher sensitivity allowed for a lower dose of radiation, and, with no need to develop film, turnaround was much quicker. The toxic chemicals and handling precautions associated with film development had also been eliminated, Mandelkern says.

But the company saw additional benefits to CMOS sensors and began working with Fossum and his team to realize them. "There was a lot of back-and-forth between our designers and their engineers" to work out the idiosyncrasies inherent in adapting the technology for X-ray use, Fossum says.

After he and a few colleagues founded the company Photobit in 1995, with an exclusive license for the technology from the California Institute of Technology (Caltech), which manages JPL, Schick in turn got an exclusive sublicense from Photobit and began producing CMOS-based dental imagers. Later, when Fossum sold his company, Schick obtained an exclusive license from Caltech for the use of CMOS-APS technology for dental imagery. It's a license the company holds to this day and one that has paid off handsomely, for both Caltech and Sirona.

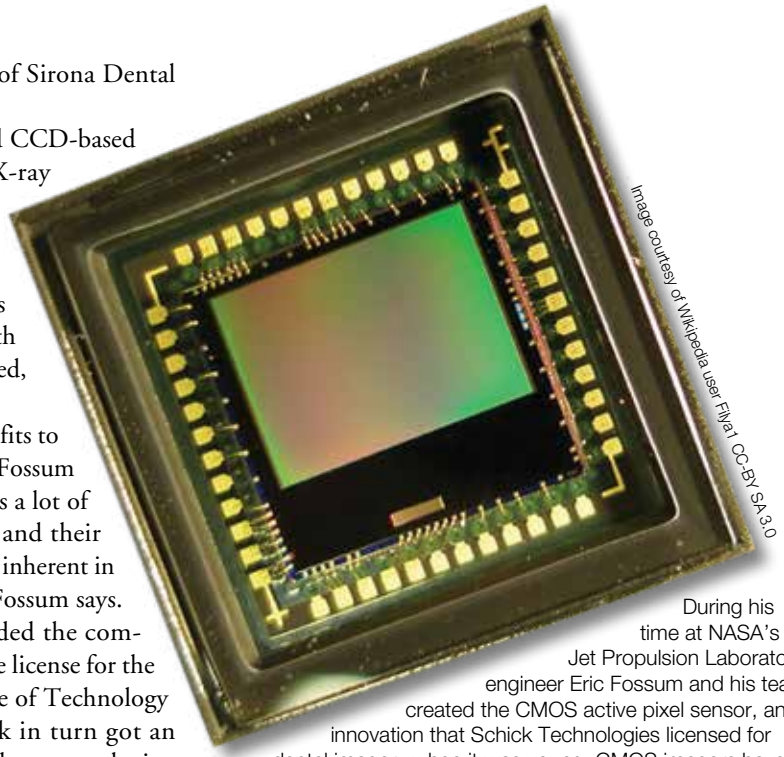


Image courtesy of Wikipedia user Fiya1 CC-BY SA 3.0

During his time at NASA's Jet Propulsion Laboratory, engineer Eric Fossum and his team created the CMOS active pixel sensor, an innovation that Schick Technologies licensed for dental imagery when it was young. CMOS imagers have since taken over the digital imaging industry.

Benefits

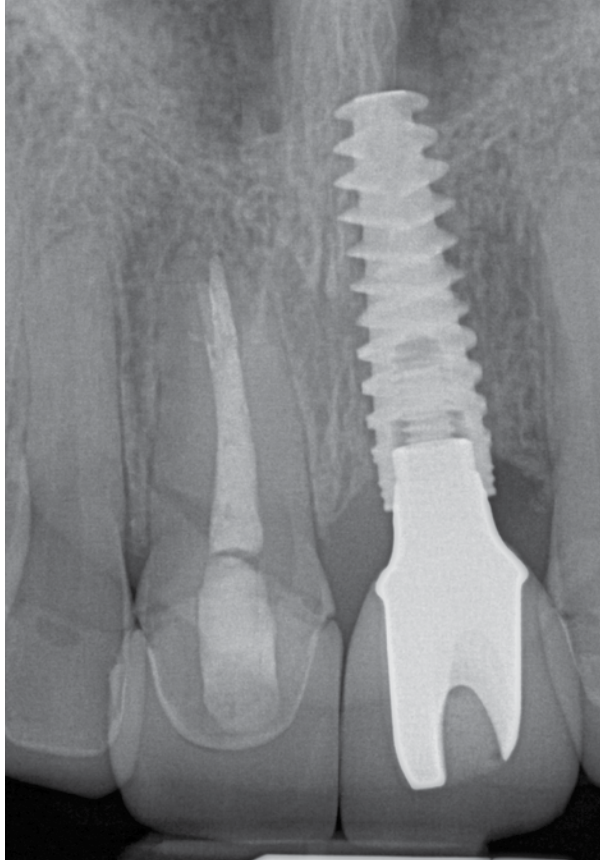
X-rays can't be focused with lenses, so the array of pixels in a digital X-ray imager has to be the size of the object being observed, says Mandelkern. That means a lot of pixels. A CCD-based array has to transfer each pixel's charge from pixel to pixel through the array with virtually no losses and requires a relatively high voltage. The more pixels, the greater the overall potential for loss. "If you lose even a small fraction of the charge as it's moving through the array, you really have almost no charge output at the end," he says. "Our array was really pushing that parameter with CCDs."

CMOS pixel arrays, able to convert each pixel's charge to a digital output, proved more efficient, which was important for devices the company wanted to power with batteries, says Mandelkern.

Since most of the camera electronics could be integrated onto the CMOS sensor chip, devices could be smaller, which, in the case of intraoral X-ray sensors that go inside the mouth, translated directly to patient comfort, he adds. And, he says, a CCD system was more susceptible to electrical noise than a CMOS imager, where the signal is processed directly on the chip. "If you can keep everything on one piece of silicon, you get higher signal integrity at lower power and lower cost."

CMOS imagers also give the radiologist the ability to get a low-resolution preview or check for exposure using a quick readout from a few pixels using minimal energy, whereas a CCD-based imager would have to read out the entire array, he says.

For a long time, CCD technology retained an advantage in panoramic imaging—say, of a full jaw—by using



An X-ray by one of Sirona's CMOS-based digital X-ray devices shows a tooth implant. Through Schick Technologies, which it acquired in 2006, the company holds an exclusive license for use of the NASA-invented technology for dental imagery.

a technique called time delay integration to create a single image from multiple frames, Mandelkern says. With the advent of fast frame-readout CMOS imagers, though, that integration can now be carried out by software in post-processing, he says.

In recent years, as CMOS sensors have been adopted across the imaging industry, intense research and development have led to rapid improvements in their size, speed, memory, and quality. Cell phone cameras in particular have driven the advancement and cheap mass-production of CMOS-APS sensors.

"We were able to take advantage of that and leverage that for our product line as well," Mandelkern says. "We're benefiting from the same processes and improvements the rest of the electronics world has benefited from."

> "If you look at what we're able to do today, there's a level of sophistication made possible that translates directly to better diagnosis and treatment for the patient."
>
> — Stan Mandelkern, Schick

For the patient, advanced digital dental imaging means lower exposure to potentially harmful X-rays, and it gives dentists images they can manipulate to make more accurate diagnoses, as well as communicate problems to the patient visually, Mandelkern says. "If you look at what we're able to do today, there's a level of sophistication made possible that translates directly to better diagnosis and treatment for the patient."

The company's latest development in CMOS is three-dimensional imaging that's being pioneered at Sirona's German location, he says. "We continue to use CMOS as the starting point for our imaging products."

Although Sirona still holds an exclusive license to use CMOS-APS technology for dental imaging, "other companies can sublicense to be able to use the technology," Mandelkern says. "Today, a lot of companies that compete with us sublicense the technology from us."

Mandelkern says this success was anything but predictable in the early days of the fledgling company's NASA partnership. "In 1997, looking at this technology at all was very risky and required a higher level of technical awareness than other companies in our industry were able to compete with us on," he says. "That's what our company has always stressed—innovation and keeping an eye on what's happening in technology and how we can leverage that in our product line."

Fossum credits JPL's cooperative agreements with companies like Schick for turning his experimental technology into successful products. "That program was critical for getting Schick going and for getting us going." ❖

Basing its dental X-ray devices on CMOS image sensors has allowed Schick and parent company Sirona to make the devices smaller and more energy-efficient, which is important for battery-operated technology.

Schick's dental imagers have benefited not only from the initial enhanced capabilities of NASA-invented CMOS image sensors but also from the rapid improvements and lower costs that have come with the technology's explosion across the digital imaging industry.

Mini Heat Pipes Wick Away Heat in Brain Surgery

NASA Technology

Neurosurgery is one of those things where you want the tools to be as precise and reliable as possible. One important tool of the trade, bipolar forceps, uses electricity to cut and cauterize tissue.

But electricity produces heat, and to avoid singeing healthy brain tissue, there needs to be a way to safely draw out that heat. One method to do that is a technology that owes a lot of its development to NASA funding and has proven useful to the Agency in a number of ways over the years.

The technology is called heat pipes, and they do one specific thing extremely well: they move heat.

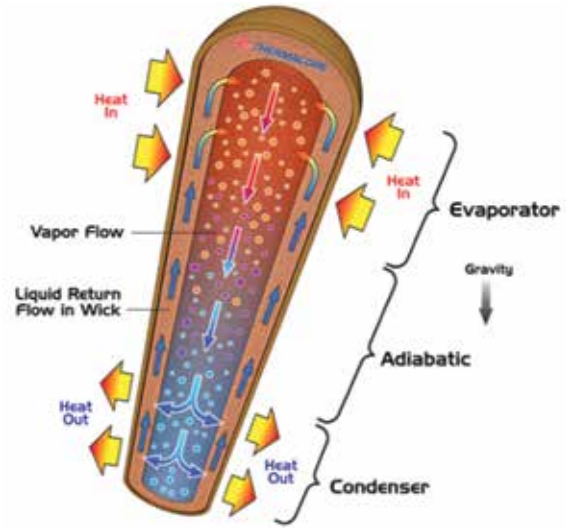
Heat moves naturally. For example, hold a piece of metal while someone heats the other end, and before long your end will get hot. Just how fast that heat gets there depends on the type of material you're holding.

One metal that conducts heat particularly well is copper. Its thermal conductivity registers at around 400 watts per meter per degree Kelvin (W/mK), explains Glenn Research Center's Kenneth Burke.

In contrast, the electrical engineer says, "you can find heat pipes that have effective conductivity that is 20,000 W/mK or greater. They're like a superhighway for heat."

Heat pipes have been around for decades, and the modern-day versions still use essentially the same principle as the earlier models. You have a vessel—usually tubular, like a pipe—and inside, held in a vacuum, there is a wick structure and a small amount of liquid.

"Heat pipes work a lot like buildings with boilers and radiators," Burke explains. The boiler heats up water and creates steam, which travels through the pipes until it gets to the radiator. The steam heats up the metal, which then loses some heat where it is in contact with the cooler air of the room, cooling the steam until it turns back into water. The water flows down the pipes back to the boiler, where the cycle repeats.



Heat pipes help dissipate heat or move it where it's needed. Thermacore makes them in a variety of sizes and configurations for different applications, but they all work based on the same basic design.

A heat pipe does basically the same thing: "It uses the hot vapor as a way to transmit heat quickly and efficiently," Burke says. By playing with the details—the shape of the vessel, the wicking material, or the liquid inside—engineers can create a tool that works for a lot of different settings.

NASA has been interested in heat pipes since the early days of spaceflight, when it found that the stark temperature differences between the sun-facing and non-sun-facing sides of a nonrotating satellite could cause failures in the electronics within. An early version of a heat pipe helped carry heat to the colder side, evening out temperatures.

More recently, the Agency was working on a way to passively cool fuel cells, which produce electricity from reactants like oxygen or hydrogen. The process produces heat, and that heat needs to be removed, Burke says. There are different ways of doing that, but having worked with heat pipes before, and specifically with Lancaster, Pennsylvania-based Thermacore Inc., Burke was interested in exploring whether the company might have a good solution for the fuel cells.

Technology Transfer

Thermacore was founded in 1970. "Our founders were working with RCA developing technologies for the space industry when they came across the concept of a heat pipe and found some ways to improve upon it," explains Thermacore medical market development manager Michael Bucci. They started a company to further develop and commercialize heat pipe technology.

Since then, Thermacore has received more than 40 Small Business Innovation Research (SBIR) contracts from NASA, starting with a 1983 project to explore the use of heat pipes in thrust chambers. More than 30 years later, the collaboration on heat pipe research is still going strong.

For fuel cells, which stack together like a deck of cards, NASA needed something that could fit between the layers. Burke went to the company to ask if they build a flat heat pipe that would absorb heat and send it to the edges.

Thermacore was able to build a very strong, lightweight heat pipe out of titanium that was just one millimeter thick.

> “There are lots of applications where heat needs to get removed from very tight spaces.”
>
> — Kenneth Burke, Glenn Research Center

The result, called ultra-thin vapor chambers, won a 2014 R&D 100 Award as one of the 100 most technologically significant products introduced in the marketplace that year (*Spinoff* 2015).

And although NASA has shifted its plans for fuel cells and isn’t using the heat pipes right now, Burke says he has no doubt the innovative design will come in handy in the future.

“There are lots of applications where heat needs to get removed from very tight spaces,” notes Burke. “NASA finds this a lot because we’re always trying to cram 10 pounds of heat-producing electronics in 5-pound boxes.”

Benefits

But fuel cells aren’t the only tight spaces where Thermacore has used heat pipes. One spot where the technology has proven very beneficial is the human brain, where surgeons need to disturb as little tissue as possible.

Bipolar forceps are two-pronged tools that use electricity to cauterize or ablate tissue between the tips. The problem was that the electricity also generates heat in the forceps, which can damage surrounding tissue—with tissue sometimes even sticking to the heated forceps, explains Bucci.

“Mini heat pipes help regulate temperatures at the tips so surgeons can control exactly where the cauterization is taking place. The result was a dramatic improvement in surgical precision, reduced procedure times, and better patient outcomes,” he says.

The heat pipes for bipolar forceps needed to be extremely small, much like the hyper-thin heat pipes for the NASA fuel cell project, which came later. Bucci says the final product is just 2.2 millimeters in diameter.

“As a heat pipe gets smaller, the amount of heat it can transfer decreases,” he notes. “So to design one small enough to fit into the bipolar forceps and still operate with and against gravity, our engineers needed to optimize the wick structure and fluid charge.”

But brain surgery is not the only medical application for Thermacore’s products. One of the earliest medical uses, in the mid-1990’s, Bucci says, was in X-ray machines, where heat pipes were used to draw out the heat created by the electron tubes that generate X-ray beams. In the years since, the company’s heat pipes have been used in a range of medical contexts.

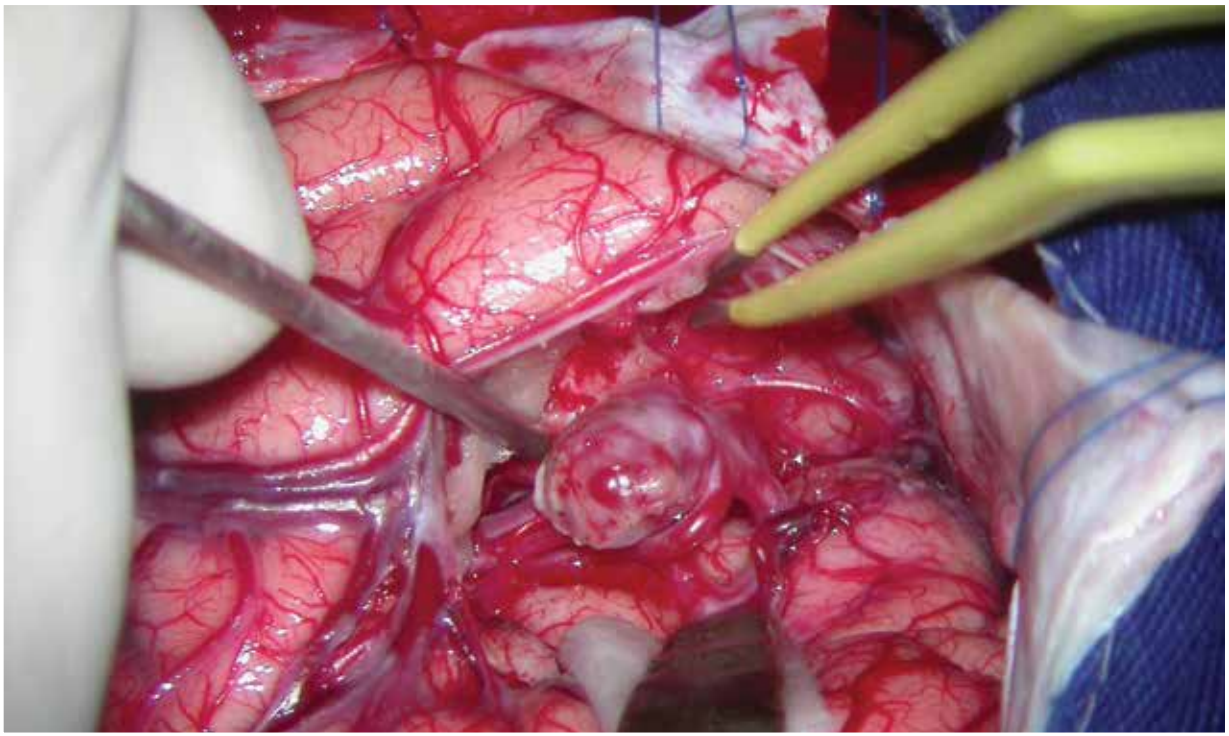
“They’re used in robotic surgery systems as well as in lasers, PET-CT scanners, PCR thermal cyclers for DNA analysis, blood analyzers, devices used to ablate cancerous lesions, and many other applications.” he says.

Another important application is in blood warmers. “Healthcare providers often need to rapidly warm blood that has been in cold storage. Our flat vapor chamber heat pipes can help spread heat more evenly across the cool blood to increase the warming rate without creating hotspots that can damage blood cells.”

Bucci says he expects the medical industry to continue to find more applications for heat pipes as the technology continues to evolve and more designers become aware of the benefits it offers.

“This is one of many examples where a technology that NASA has contributed to finds other uses that are not so obvious,” says Burke. “The technology almost has to exist before someone in a medical field says, oh, we might be able to use a heat pipe here.”

“NASA investigated these because it had a problem first and looked for a solution. But oftentimes, once the solution exists, it ends up looking for a problem. And that’s where spinoffs come about.” ❖



A surgeon uses bipolar forceps (yellow) in an operation to repair an aneurysm. Thermacore has designed a miniature heat pipe to help dissipate extra heat generated by the electricity in the forceps, which has improved surgical precision, reduced procedure times, and improved patient outcomes.

Fluorescent Diagnostic Test Readers Offer Fast, Low-Cost Results

NASA Technology

NASA astronauts are screened for sound health, among a slew of other requirements, but no one is invulnerable, especially in space. For reasons not fully understood, space travel appears to suppress the human immune system, while some bacteria become heartier and more virulent in microgravity. Meanwhile, aboard the International Space Station, the nearest medical doctor is on the other side of atmospheric reentry. On a future mission to Mars, any emergency return would likely take months.

As part of NASA's Exploration Medical Capability Element, it's Ames Research Center engineer Tianna Shaw's job to minimize the chance of such an emergency ever arising. Among the tools she and other NASA researchers want to use to that end are rapid diagnostic tests capable of detecting health problems accurately and early on.

"We don't currently have lab technologies we use terrestrially that are of a size that would be acceptable for use in space, at least not on an exploration mission," Shaw says. Blood work, for example, normally involves a few samples being taken and sent to different locations where they're analyzed using the kind of heavy, bulky tabletop equipment that would cost a fortune to launch into space. What Shaw and her colleagues want instead would more resemble a home pregnancy test, with a single sample analyzed by one small device that produces results within minutes.

In 2011, Ames awarded two Small Business Innovation Research (SBIR) contracts to Intelligent Optical Systems (IOS) to deliver just that. The company proposed integrating a sensor platform with a smartphone, taking advantage of the existing technology's high-resolution camera, processing power, and compactness. For the sensor, IOS envisioned using what's known as a lateral flow test strip, the same detection technique used in a pregnancy test. The strips would analyze bodily fluids by combining them with molecules that glow in ultraviolet light and also bind with certain biomarkers—substances that indicate a biological condition, such as antibodies that signal the presence of specific illnesses.

IOS specializes in this sort of diagnostic testing, among other products, but to build the smartphone interface, the company turned to Los Angeles-based Holomic LLC, now Cellmic, which was already marketing smartphone-based diagnostic hardware.

Technology Transfer

"Our instruments already had a reputation for being highly accurate, so that was the motivation," Cellmic cofounder and CEO Neven Karlovac says of IOS's decision to subcontract his company. "Basically, IOS's task was to develop the tests themselves, and our task was to develop a smartphone-based electronic reader to accurately read those tests."

Cellmic already had a similar reader for analyzing test results in the visual spectrum. To meet NASA's needs, the company developed a version that illuminated the test strips with ultraviolet light and could use the phone's microprocessor to evaluate the resulting images and determine whether or not a given biomarker was present.

Because the tests use particles that become fluorescent in ultraviolet light, the results are easier for the system to spot, making the tests more sensitive than traditional, chromatographic lateral flow strip assays. "I guess you could look at it as an amplification method," Karlovac says, noting that a lower number of particles can be detected if they're emitting light rather than just reflecting it.

The NASA funding, through the IOS subcontract, let the company develop the concept, lighting, electronics, and software to make the device possible, he says. "It was instrumental in enabling us to do the research and development work."

The two companies also worked together to ensure the tests and reader were compatible, and they ultimately delivered the capability to rapidly detect one cardiac and three liver biomarkers. "There was a considerable amount of effort and collaboration in developing the tests and reader in parallel," Karlovac says.

> "[The advantages] are the speed and low cost and the fact that the results are available onsite while the patient is there and that the tests are relatively easy to administer."
>
> — Neven Karlovac, Cellmic LLC

Benefits

The device Cellmic commercialized after the work was done, though, is designed to be compatible with a wide variety of tests. Rather than selling complete test kits to end users, the company markets its HRDR-300 Fluorescent Immunoassay Reader, available as a smartphone attachment or in a benchtop version, to companies that want to develop their own tests. The devices' software is designed to be flexible and can be programmed according to the test developer's needs.

The reader was officially released at the American Association of Clinical Chemistry meeting in July 2014. "We've delivered to a number of customers, and they're using the product in their own development of these tests, or they're validating their tests in clinical trials," Karlovac says, adding that he hopes the technology will go into clinical use shortly.

Handheld, rapid diagnostic tests present several advantages: "speed and low cost and the fact that the results are available onsite while the patient is there and that the tests are relatively easy to administer," Karlovac says. "And because it's a networked device that gets digital results and is portable, it's good for remote applications." The same qualities that make the technology essential for deep space exploration also make it useful in far-flung corners of Earth.

The communications capability enabled by the devices' smartphone platform also gives them another advantage. Test results, along with the locations where they are obtained, can be transmitted to a central database. In the event of a disease outbreak, Karlovac says, crews of health authorities using the readers would end up mapping cases of the illness. "You can see where there are more positive cases and how they move around so you can monitor the spread of the disease."

Next, he says, Cellmic plans to devise a reader that can automatically adjust to analyze test results in both the visible and ultraviolet ranges. And NASA again plans to help fund the technology's development.

Different light filters are required for tests that use different parts of the spectrum, and NASA would like the filters to change automatically, depending on the test. "We want to use this in space, and we don't want to have to manually change the filters. They're very small," Shaw says. She thinks the additional versatility will benefit Cellmic's earthbound products, too. "What they'll gain here is something they wouldn't necessarily do terrestrially, but I expect that it will eventually be incorporated into their commercial systems," she says.

She doubts that NASA's work with the company, which is also pioneering other rapid, mobile diagnostic tests, will end there. "One nice thing about the other tests Cellmic has is that by the time I need them for my exploration system, I believe they'll have those capabilities to choose from." ❖

Image courtesy of the U.S. Navy

Cellmic's smartphone-based test reader presents several advantages for medical field work in remote locations, such as portability, ease of use, speed of test results, and the ability to transmit diagnoses and geographical locations to a central database, for example to map the spread of an outbreak.

As a NASA subcontractor, Cellmic LLC (formerly Holomic LLC) developed a sensor platform that uses a smartphone's camera and processing power to read the results of custom-made rapid diagnostic tests of bodily fluids.

Cooling Garments Find New Medical, Athletic, and Industrial Uses

NASA Technology

When Bill Elkins started working on liquid cooling garments to keep early astronauts cool, no one saw a use for them beyond maintaining thermal comfort. In the decades since, however, Elkins and other engineers have applied these wearable devices to a surprising number of industries and medical problems. Now, almost 60 years after his first encounter with the technology, he's still spinning off his expertise in using liquid to regulate body temperatures.

Image courtesy of the San Diego Air and Space Museum

Bill Elkins poses in the Advanced Extravehicular Suit he designed for NASA in the 1960s as a contractor working for Garrett AiResearch. Elkins' work on liquid cooling garments to be worn under NASA spacesuits and Air Force flight suits led him to commercialize a number of liquid cooling technologies.

The first liquid cooling garments were developed by the British Royal Air Force for pilots sweltering in hot cockpits. Worn under the uniform, they consisted of tubes threaded through long underwear with water pumped through them and cooled by a heat exchanger. The U.S. Air Force, which managed the planning for the Mercury missions until NASA was formed, soon began modifying the design for spacesuits. Elkins, a former fighter pilot with a degree in industrial design, joined the effort at the start and worked on the garments as a contractor to both NASA and the military.

In 1962 Litton Industries hired Elkins to develop rigid spacesuits, work that he continued as chief engineer at the AiResearch division of Garrett Corporation. At Aerotherm Corporation in the 1970s, he worked with several engineers at NASA's Ames Research Center to develop an astronaut liquid cooling garment that used cooling panels, rather than vinyl tubing, a concept he would build on in later work for the Defense Advanced Research Projects Agency and a number of his own companies.

He and engineers at Ames designed a system of thin panels holding liquid-filled channels, each covering a muscle mass and connected by minimal tubing. They also introduced a cooling system for the helmet.

The system was never used in space, but these elements would appear in Elkins' later commercial creations.

Technology Transfer

In the late 1970s, NASA contracted Acurex Corporation, where Elkins was then working, to design a liquid-cooled helmet liner and vest for helicopter pilots and then partnered with the company and the U.S. Bureau of Mines to create a body-cooling system for mine rescue workers.

Elkins founded Life Support Systems Inc. in 1980 and developed a number of cooling systems for military, recreational, and industrial applications. He began adapting his device for medical uses when Ames connected him with a parent whose child was born without sweat glands, a condition known as hypohidrotic ectodermal dysplasia.

Elkins created a cool suit to help the child and others like him, and the attention it received prompted others to bring him ideas for additional medical uses. As a result, his company ended up again working with Ames engineers, including Bill Williams, Bruce Webbon, Vic Vykukal, Bernadette Luna, and others who had made important contributions to liquid cooling garment technology. The team developed a treatment for multiple sclerosis, which doctors had been treating with cool baths since the late 1950s. The disorder results from damage to the protective sheathing, known as myelin, around nerves in the brain and spinal cord, causing nerve impulses to "short circuit." Doctors found that lower temperatures allow signals to transmit more reliably along damaged nerves.

The Mark VII MicroClimate Medical Personal Cooling System (*Spinoff* 1993) Ames and Elkins created focused on cooling the brain with a liquid-cooled cap and vest, as opposed to cool baths, which were uncomfortable and could have unwanted side effects. The devices also came to be used to treat symptoms of peripheral neuropathy, epidermolysis bullosa, spina bifida, and cerebral palsy.

The military has also used Life Support Systems' cooling technology, for example to keep armored bomb squad personnel cool in scorching temperatures during operations Desert Storm and Desert Shield, an application that won Elkins a Commander's Award for Public Service from the Army.

Elkins was one of several engineers from industry and Ames, as well as Johnson Space Center and Langley Research Center, inducted into the Space Foundation's

“It’s a very powerful, **non-physically** invasive **therapy.”**

— Bill Elkins, WElkins LLC

WElkins LLC’s Sideline Cooling System is marketed to athletes and sports teams as a way to improve performance, reduce inflammation in the event of a concussion, and reduce the effects of minor head impacts.

One application for WElkins LLC's NO SWEAT! Work Enhancement System is to cool workers who have to wear heavy protective clothing, such as bomb squad personnel. In fact, one of his earlier companies' products earned Elkins a Commander's Award for Public Service from the Army for its usefulness in cooling these military personnel during operations Desert Shield and Desert Storm.

Image courtesy of the U.S. Navy

Space Technology Hall of Fame in 1993 for their work on liquid cooling garments.

In the early 1990s, Elkins founded CoolSystems Inc. to adapt the technology to sports therapy (*Spinoff* 2004) with a device that applied pressure and cold to injured areas. The company got off to a rough start, and Elkins sold it to investors after a couple of years, but it went on to become hugely successful and now, doing business as Game Ready, also markets similar devices for use on injured dogs and horses.

In the mid-1990s Elkins founded WElkins LLC, now based in Downers Grove, Illinois, and worked with Oceaneering International on next-generation spacesuit and restraint systems.

For all that, he says his work "really began" in 2001 when Dr. Huan Wang, a neurosurgeon at OSF Saint Francis Medical Center in Illinois, was looking for a way to cool the brains of stroke and head trauma patients and came across a drawing Elkins had created for NASA, of a head-cooling device. "NASA put him in touch with me, and we've been fused at the hip ever since," he says.

The pair collaborated on a pilot study published in 2004. Based on the potential it showed, True North Equities bought 60 percent of WElkins to continue spinning off liquid cooling systems for new applications.

Benefits

Strokes and heart attacks decrease the amount of oxygen in the brain. By lowering the brain's temperature, a doctor or first responder slows its oxygen metabolism, decreasing the need for oxygen to prevent cell damage. Traumatic brain injury, meanwhile, can also reduce oxygen delivered to areas of the brain, and cooling in this case also prevents damage by reducing inflammation.

"It's a very powerful, non-physically invasive therapy," Elkins says.

Reducing the brain's oxygen metabolism also helps prevent damage during open-heart surgeries, when blood flow is decreased. "It basically puts the nerve cells into a little bit of a hibernation, so they require less oxygen during surgery," Elkins says, noting that this was an unexpected use that Wang brought to his attention.

Today hospitals and emergency medical technician teams are some of the company's biggest customers.

WElkins' Cooling Headliner, which the Food and Drug Administration approved for medical uses in 2012, applies pneumatic pressure to increase heat transfer, and it extends over the carotid arteries in the neck to cool blood on its way to the brain, effectively cooling from the inside and outside. Elkins says it can reduce brain temperature by around 4 °F in about 15 minutes.

Elkins and his partners have found that WElkins' head liner is also effective in treating migraines and epilepsy. This is because cooling slows the speed of neural impulses: "It's like turning the treble off on your hi-fi," he says.

The company also markets a Sideline Cooling System to athletes and sports teams, saying cooling combats heat stress and improves performance by maximizing oxygen uptake, lowering heart rate, decreasing sweating, and increasing blood flow to the working muscles. Then there's the matter of reducing inflammation in the event of a sports concussion. Wang maintains that higher brain temperatures resulting from exertion can increase the brain's susceptibility to damage from minor blows. "If you use cooling on the sidelines, you reduce the effects of minor, sub-concussive impacts," Elkins explains.

Technology pioneered to keep astronauts and pilots cool now finds a commercial market in sports, where a liquid-cooled headliner can reduce inflammation in the event of a concussion and also improve performance by maximizing oxygen uptake, lowering heart rate, decreasing sweating, and increasing blood flow.

As sports concussions receive more and more attention, he says, he expects use of the Sideline Cooling System to increase.

The company has also developed a NO SWEAT! Work Enhancement System—a cooling cap and vest aimed at workers who have to wear heavy protective clothing or armor, work in hot environments, or both. These include military, firefighting, hazardous material cleanup, power plant, mining, and other applications.

Like the head liners, the cap and vest employ a system of panels similar to what Elkins designed with NASA.

WElkins did not begin marketing aggressively until summer of 2016, following clinical and athletic research partnerships with a number of colleges and universities. The company, which currently has 8 to 10 employees, anticipated roughly $1 million in sales in 2016 in the medical and athletic markets and "exponential growth thereafter," says WElkins President Christopher Blodgett, who notes that the company also provides engineering and product development for the Department of Defense and private companies, which it expected to generate about $500,000 in 2016 and $1.25 million the following year.

Asked what has kept him relentlessly spinning off liquid cooling garments for ever more applications over the decades, Elkins says, "I like to contribute to humanity, and I like to stay busy. If I can help humanity, that's what I want to do." ❖

Space-Based Bone Scanner Expands Medical Research

NASA Technology

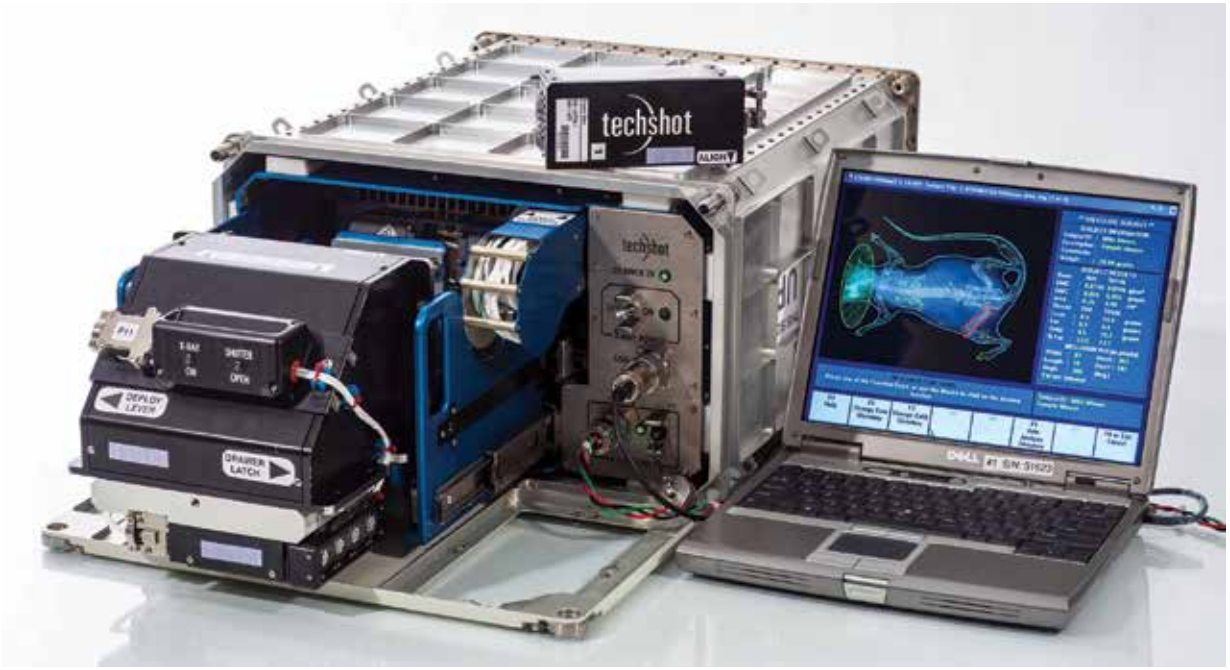
What happens to bones after months in microgravity? The answers are of keen interest to researchers, who can use the information to offer new insights into healthcare on the ground.

But since research space is at a premium on the International Space Station (ISS), cutting-edge equipment is needed that can help ground-based researchers connect with the orbiting lab. When it came to studying bone density, NASA wanted a scanner that wouldn't expose the astronauts using it to harmful radiation.

Part of the challenge was that much of the research hardware on the ISS, which orbits some 250 miles above the Earth's surface, was loaded years or even decades ago, and its equipment is growing out of date. "That was a little tough to swallow, but it's true," says Mike Read, manager of the ISS's United States National Laboratory Office at Johnson Space Center. He'd been a part of the team in the payloads office in 1996, shortly before on-orbit assembly of the station began, and returned there in 2012, around the time it was becoming apparent that the lab facilities needed an upgrade.

"What we've been doing is to upgrade our capabilities to mimic what's in a terrestrial lab," Read says.

For NASA's would-be commercial partners, it is important that any research equipment added to the ISS be similar to tools used on the ground, to allow for comparable test results and to justify the extra expense of sending trials to space. As a part of its upgrade effort, the Agency turned to the Center for Advancement of Science in Space (CASIS) to help get newer equipment ready for space.



Techshot worked with NASA and the Center for the Advancement of Science in Space to develop a commercial bone densitometer suitable for operation on the ISS. The device, dubbed Bone D, is primarily used by companies to study the effects of microgravity on mice.

Technology Transfer

Since 2011, CASIS has been responsible for lining up commercial clients for the ISS as the manager of the National Laboratory—the part of the ISS's research facilities owned by the United States. CASIS selects projects based on commercial proposals and provides funding from a $3 million budget. The organization also connects clients with additional investors.

For equipment that researchers could use to study bone health in microgravity, particularly by scanning the bodies of small animals such as mice, CASIS got in touch with Greenville, Indiana-based Techshot.

"Techshot has more than 25 years of experience with NASA," says Mike Roberts, a senior research scientist at CASIS. "Since 2011, they have been working with us to design new tools and facilities for space research and to support the development of life-science payloads for ISS National Lab customers."

Techshot, awarded a Small Business Innovation Research contract, determined that an existing method for measuring bone density—known as dual-energy X-ray absorptiometry (DXA)—was a good starting point. With funding from NASA and CASIS, the company began an 18-month sprint to build and qualify a DXA device for use on the ISS.

Techshot started with a device widely used by biomedical researchers to take X-rays of rodents, called the GE Lunar PIXImus X-ray densitometer. In order to fit into the hardware racks, also called lockers, aboard the ISS, the company had to modify the device to make it smaller and lighter. However, Techshot was able to keep the same software, operating system, and display, allowing ground-based scientists to make apples-to-apples comparisons between ISS scans with those taken on Earth.

Wary of a radiation-emitting device in close proximity to the ISS crewmembers, the company equipped the densi-

Through an agreement with NASA, astronauts conduct the experiments that use Techshot's bone densitometer. The company maintains a payload operations center from which it can monitor its space-based equipment and download data in real time.

tometer with extra lead shielding and included a switch to ensure the device does not function unless secured into its assigned locker on the station. Even if something went awry, says Rich Boling, Techshot's vice president for corporate advancement, the astronauts aren't in much danger from the device's radiation: "Crewmembers get more of a dose of radiation from eating two bananas than the X-rays being emitted from our machine. Before I learned that, I didn't even know bananas had radiation in them."

Benefits

With a bone-scanning device operational on the ISS as of April 2015, researchers for the first time have the ability to observe changes in test animal musculature and bone density in space in real time, a boon for biologists and pharmaceutical companies interested in developing treatments for musculoskeletal ailments.

Techshot and CASIS quickly secured Novartis as the first client to use the densitometer. (As part of its contract with NASA and CASIS, Techshot is responsible for maintaining the device and helping bring in commercial clients, while the ISS crew conducts the investigations.) Novartis, the pharmaceutical giant based in Cambridge, Massachusetts, wanted to explore muscle atrophy using genetically modified rodents, in which the Muscle RING Finger-1 gene, associated with muscle protein degradation, was "silenced."

Sam Cadena, investigator for the Muscle Group at Novartis, says his company leapt at the opportunity to conduct research on the ISS, as it provides a "unique model" for degeneration. "The only other model that can replicate this on Earth is aging. Thus the microgravity environment of the ISS provides a model for aging in only a fraction of the time," he says.

Novartis scheduled two investigations, each involving two groups of more than a dozen mice—one group on the ground in a new facility at Kennedy Space Center and the other on the ISS. Half the mice in each location contained modified genes, while the other half were unmodified, allowing researchers from Novartis to compare differences in musculature after 45 days. (A second investigation, originally scheduled for fall 2015, was delayed after the loss of the SpaceX Falcon 9 earlier that year.)

To conduct the investigation, crewmembers exposed mice to X-rays for three minutes, and the scans were relayed to Techshot's payload operations center almost in real time for review by Earth-based researchers.

Today, the bone densitometer, dubbed Bone D, is "a permanent resident of EXPRESS Rack 7," Boling says with pride. Right now it's only being used for rodent research, although it's possible other living creatures could be scanned with it in the future.

NASA's grateful for the increased capability on the ISS, Read says. "We're committing a significant amount of our research crew time to enabling the rodent investigations. Bone D is a big part of the effort. This is an analytical capability we didn't have before. It's one of the holes we're trying to fill, and that's where Techshot came in."

Other companies are in talks with CASIS and Techshot to get time on the densitometer, and the company is happy with its potential role in the future of research on Earth and in space.

"For a company of 30 people, we're terribly excited about this; it's our flagship product right now," Boling says. "To be able to own it, operate it, be responsible for it as a commercial model, as a commercial venture—this wasn't possible a few years ago. The fact that a company would maintain its commercial hardware orbiting the Earth at 17,000 miles per hour as a small business? We're excited about the future and what it may hold for companies like Techshot." ❖

Temperature-Regulating Fabrics Keep Babies Comfortable

NASA Technology

NASA's astronauts are among the world's most capable, resourceful, and highly trained individuals. Now technology originally created to keep them comfortable in space is available to the population's most helpless and inexperienced members—babies.

A spacesuit is, by necessity, almost impermeable to temperature. While its many layers of insulation protect the wearer from the extreme temperatures on its outside surfaces in space, they also work the other way, holding in body heat that, if not regulated, would quickly become uncomfortable. One method NASA investigated in the 1980s for managing heat inside a spacesuit was the use of phase-change materials (PCMs).

Like ice cubes in a drink, these materials steadily absorb heat as they change phase from solid to liquid, and, if exposed to colder temperatures, they release that heat as they refreeze. The trick was finding materials that could hold more heat and transfer it more quickly than water and would change phase at a temperature comfortable to humans. The material would also have to be nontoxic and nonflammable.

In 1987, Johnson Space Center awarded a Small Business Innovation Research (SBIR) contract to Triangle Research and Development Corporation to experiment in using such materials, contained in tiny microcapsules, to create a passive spacesuit liquid cooling garment instead of one based on an active heat exchanger. Triangle had previously worked on an energy storage system using PCMs under two SBIR contracts with Marshall Space Flight Center. In 1988, the company experimented with incorporating these materials into synthetic fibers to insulate an astronaut glove under another Johnson SBIR contract.

Technology Transfer

PCMs never quite caught on for spacesuits, but a company called Gateway Technologies saw their potential for commercial applications and licensed the exclusive patent rights for incorporating the material into fabrics and fibers. Now called Outlast, the company supplies fabrics infused with microencapsulated PCMs to hundreds of companies that use them in everything from bedding to athletic clothes, dress wear, underwear, pajamas, sleeping bags, and more (*Spinoff* 1997, 2004, 2009, 2012, 2013).

Embrace Innovations' product line spun out of an MBA-student project to supply baby warmers to populations lacking access to modern medical care. Today, every item purchased from the company results in a warmer donated to an infant in need.

While Outlast was building its robust customer base, Stanford University MBA student Jane Chen and a small team of classmates were assigned in 2007 to try to come up with an infant incubator that could be manufactured for just $200, or 1 percent of the price of traditional incubators. They hit on PCMs, came up with a prototype, and started a nonprofit called Embrace, with Chen as the CEO. Upon graduating, the group moved to Bangalore, because India has the highest number of premature births per year.

Since their final product was developed, the Embrace infant warmer has been used to treat hundreds of thousands of premature and otherwise low-birth-weight infants in populations lacking access to modern medical care throughout 14 developing countries.

"In 2012, the team realized they wanted to go forward with more innovation and spun off a for-profit, Embrace

Innovations," says Kai Chan, vice president of operations at the San Francisco-based company, where Chen is now CEO after stepping down from her position with the nonprofit.

"A couple years ago, Jane moved back to the Bay area, where many of her friends were having babies," Chan says. A common complaint among the new parents was that they never knew if their babies were too hot or too cold. Chen decided to look for a solution.

Already well familiar with PCMs, she looked for a way to use them for infant comfort and discovered Outlast. Through a Kickstarter campaign in spring of 2015, Embrace Innovations raised $130,000 and started taking preorders for a line of infant swaddles, sleeping bags, and blankets, marketed as the Little Lotus product line, all made with Outlast linings shot through with microencapsulated PCMs.

All of these products are now available for order through the company's website.

Benefits

"Our products absorb or release heat to keep babies at a comfortable skin temperature," Chan says. Fewer temperature fluctuations mean a baby rests more easily, which means the parents also rest easier, she notes.

She cites an informal study showing that 8 out of 11 babies slept on average four hours longer over a five-day period with Little Lotus products, compared to other comparable products on the market.

Meanwhile, formal studies have linked sudden infant death syndrome with overheating, which Little Lotus products reduce the risk of.

The Little Lotus line includes a swaddle for infants up to three months old, as well as three sizes of sleeping bags for babies 3 to 18 months old. Also available is a quilted blanket.

The signature Touch Our Futures pattern, available for all Little Lotus products, was created by artist Drue Kataoka and features handprints of mothers and babies from around the world who have benefited from the company's Embrace Infant Warmer.

The swaddle design includes a side-zipper that allows the front panel to open completely and a second zipper along the bottom for easy diaper changes.

"The premise behind Little Lotus is, we wanted to use the TOMS Shoes one-for-one model," says Chan. "With every product purchased, a baby in a developing country will be helped with an infant warmer." She notes that Embrace Innovations retains the same primary mission as the nonprofit it sprang from: to reduce the world's infant mortality rate by helping to save premature babies in underserved populations. To donate the warmers, the company is partnering with other nonprofits.

The warmers' removable PCM packs can be heated with boiling water or an electric heater, and reinserted to keep the warmers at about 98 degrees for up to six hours. They're portable and reusable, and they cost less than $200.

"We're using this NASA technology not just to keep babies comfortable but also to support our efforts to save premature babies around the world," Chan says, noting that the company has set a goal of helping 1 million infants. ❖

The company's NASA-derived product line includes baby swaddles and sleeping bags in various sizes, as well as a quilted blanket. Phase-change materials in the products' fabric regulate body temperatures, absorbing heat when babies get too warm and releasing it when they are cool.

Transportation

However you get around on the road or in the air, NASA is with you when you travel. Technologies developed by NASA track flights worldwide, help aircraft designers minimize the effect of sonic booms, keep commercial space cargo safe during landing, monitor vehicle carbon-dioxide emissions, and more.

Reconfigurable Radio Tracks Flights Worldwide

NASA Technology

When Malaysia Air Flight 370 disappeared somewhere over the Indian Ocean in 2014, it had flown far beyond radar range. Under a new space-based air tracking system, no plane would ever be off the grid that way—and it is possible thanks in part to a collaboration with NASA, starting with a reconfigurable radio.

NASA uses powerful radios to communicate with its satellites, rovers, and astronauts. These devices allow us to see everything from pictures of cryovolcanoes on Pluto to tweets from the International Space Station (ISS). In recent years, the Agency decided it needed radios that work on higher frequencies with more bandwidth, to make sending larger quantities of data back and forth faster, and that can be reprogrammed from a distance.

"A reconfigurable radio lets engineers change how the radio works throughout the life of the mission, if requirements change or when the environment does," explains Thomas Kacpura, Advanced Communications Program manager at NASA's Glenn Research Center. "It can also be upgraded to work better with future missions or to enhance performance, just by adding new software to the radio."

In the past, Kacpura says, engineers were reluctant to build reconfigurable devices for space because of testing requirements. They evaluated devices under every conceivable circumstance to ensure that, no matter what happened in space, the radio would keep doing its job. That's harder to do with a reconfigurable radio—after all, how do you test for functions you don't even know you'll be using?

However, Kacpura says recent missions have been allotting a larger size, power, and weight margin for reconfigurable systems. In addition, the culture has evolved and has become more comfortable with in-flight changes, which led NASA to design and develop a new reconfigurable, higher-bandwidth radio with Palm Bay, Florida-based Harris Corporation through a 50/50 cost-share cooperative agreement.

NASA wanted a higher-frequency space-based radio that can be reprogrammed from a distance. Harris Corporation worked with the Agency to design one, and is now selling them commercially as the AppSTAR. In this artist's rendering, the radio is mounted on the satellite under a white cover.

“Within seconds you can keep **track of** all the **aircraft in the world.”**

— Jeff Anderson, Harris Corp.

This map plots scheduled flights—more than 50,000 of them—from June 2009. With Aireon flight tracking, air traffic control agencies will be able to see, in real time, the location and heading of every plane in the air.

Image courtesy of Wikipedia user Jpatokal, CC BY-SA 3.0

The result of that effort was tested as part of the Space Communication and Navigation (SCaN) Testbed, an experimental communication system on the ISS. The SCaN Testbed project is led by Glenn and was developed in cooperation with the Jet Propulsion Laboratory, Goddard Space Flight Center, Johnson Space Center, industry, academia, and international space agencies, all of whom also currently support experiment activities.

"The Harris SDR is the first space-qualified, software-defined radio in Ka-band," Kacpura says. Ka-band frequencies offer data transmission rates that are much faster than the previous standard and is considered a key part of future NASA space communications.

The radio has been put through its paces through exhaustive testing both on the ground and in space, has been reconfigured and reprogrammed, and has performed well. In 2013, it was honored with an R&D 100 Award as one of the year's top 100 most significant innovations.

"This is a big leap," Kacpura says. "With a few tweaks and updates based on the test runs, this radio could now become the high-speed data radio on any spacecraft," he adds. This will help get data back to Earth even faster than before, expanding the science return of NASA missions.

Technology Transfer

The company knew the work it was doing with NASA was going to pay off with its other customers, but, says Harris systems engineer Jeff Anderson, "to be honest, I think we were surprised at just how quickly it was embraced both by our own designers and by customers."

The biggest selling point of the new device turned out to be its flexibility. It can be fully reconfigured both in its hardware and its software, explains Harris program manager Kevin Moran, which meant the company could quickly and cheaply redesign it to fit any customer's needs. Basically, "this is a box, and inside there are a bunch of cards that plug in," Moran explains. "Power supply cards, a processor card, and then there are the cards specific to that mission. So when a customer has a different mission, we only have to change out a subset of the hardware within the box."

Harris has trademarked the radio, which it calls the Harris AppSTAR, and has already sold it to a wide range of clients.

Benefits

One of the biggest contracts so far is with Aireon LLC, which has engaged Harris to develop a hosted payload for new Iridium Communications Inc satellites. For the last two decades, Iridium has operated a constellation of satellites in low-Earth orbit, which makes it possible to make phone calls or send data to and from the world's most remote regions. Unlike other satellites, each of the cross-linked orbiters can communicate with the others, meaning every point on Earth is always within coverage of the network.

In 2016, the company began launching its Iridium NEXT constellation of satellites, with a higher bandwidth and increased capabilities, including Harris AppSTAR radios. Aireon, a joint venture formed by several companies to take advantage of the constellation, will use the radios to create the first space-based global air traffic control system.

For decades, airplanes have relied on radar surveillance, which needs land-based radar stations to receive and transmit signals. That's left

With real-time flight tracking, planes can safely optimize their flight routes and fly with less space between them. And if a plane disappears, emergency responders will have exact tracking information to start their search.

> “This is a big leap. With a few tweaks and updates based on the test runs, this radio could now become the high-speed data radio on any spacecraft.”
>
> — Thomas Kapcura, Glenn Research Center

huge gaps—particularly over oceans—where air traffic controllers have no real-time information about a plane’s location or heading. To compensate, pilots file detailed flight plans and are required to remain within prescribed lanes at different altitudes so air traffic controllers can estimate where they are and work to ensure there are no mid-air collisions.

But that is all set to change when the 66 Iridium NEXT satellites go into orbit, equipped with Harris AppSTAR radios. The AppSTARs are programmed to receive signals from new airplane transceivers called ADS-B, which automatically send out the flight number, location, heading, and other flight details.

Currently, similar data is transmitted to other airplanes in the area and also collected by terrestrial receivers on the ground. Anderson points out, however, that the receivers require a line of sight to communicate, so as soon the airplane goes over the horizon, receivers on land can no longer detect the signal. As a result, many planes flying over the ocean and other remote areas can’t be tracked at all.

Putting the receivers into orbit solves that problem. “Within seconds you can keep track of all the aircraft in the world,” says Anderson. Aireon has already signed contracts with a number of air traffic control agencies to integrate the space-based system into their flight tracking when the system goes live in 2018.

Nav Canada, a founding partner in Aireon, was one of the first. “Think of the size of Canada,” says Moran. “If they were going to take advantage of this ADS-B system, they would have to go through this massive terrestrial build-out in very remote locations. The alternative is a space-based system.” Agencies in many other countries, including the U.S. Federal Aviation Administration, have also expressed interest.

With real-time global tracking, airlines will be able to optimize their air traffic control patterns, Anderson explains. Planes can fly with less space between them, as well as take more direct routes. “It tremendously improves public safety and potentially saves a lot of fuel costs, because you no longer have to remain in the particular airline traffic lanes.”

And when something does go wrong, like with the Malaysia Air flight that disappeared, search and rescue teams will have detailed information on where to look, because the satellites will receive tracking information from every airborne plane, even those in areas not subscribing to the Aireon tracking system. “Aireon will provide a free service, which they call Aireon ALERT (Aircraft Locating and Emergency Response Tracking), through which, if there is an airline issue, they will provide the last track that they have in their system,” Anderson says.

The AppSTAR radios on the Iridium satellites were designed with extra space, Anderson adds, so Harris was able to add yet another function: the same kind of global tracking for ships, which the company markets as exactAIS RealTime, powered by Harris with their partners exactEarth.

“We’ve taken that reconfigured processor card and changed it a little bit yet again,” says Anderson, and now it can address the maritime VHF frequency range, which broadcasts automated ship tracking. Out on the open ocean, ships can communicate with each other but not with the terrestrial system. Adding just one more card to the AppSTARs hosted by Iridium, however, suddenly allows any shipping company to know where its vessels are and track the shipping lanes worldwide.

And because the AppSTAR software can be reconfigured remotely, both the Aireon and exactAIS systems can be updated well after launch, “if we need to modify them, or if we need to change them for future changes in the architecture or formats,” he says. “We can make the changes off into the future.” And it all started with the same box, processor, and power supply cards as the NASA radio.

“I remember our first discussions with NASA Glenn in 2008,” says Janet Nickloy, vice president of Responsive ISR Programs, Space and Intelligence Systems. “We knew we had a good idea, but we never imagined it would lead us to where we are today. Working together, we not only furthered the NASA mission, but will make air and marine travel safer for the global community. I can’t wait to see where we go next.” ❖

Design Software Shapes Future Sonic Booms

NASA Technology

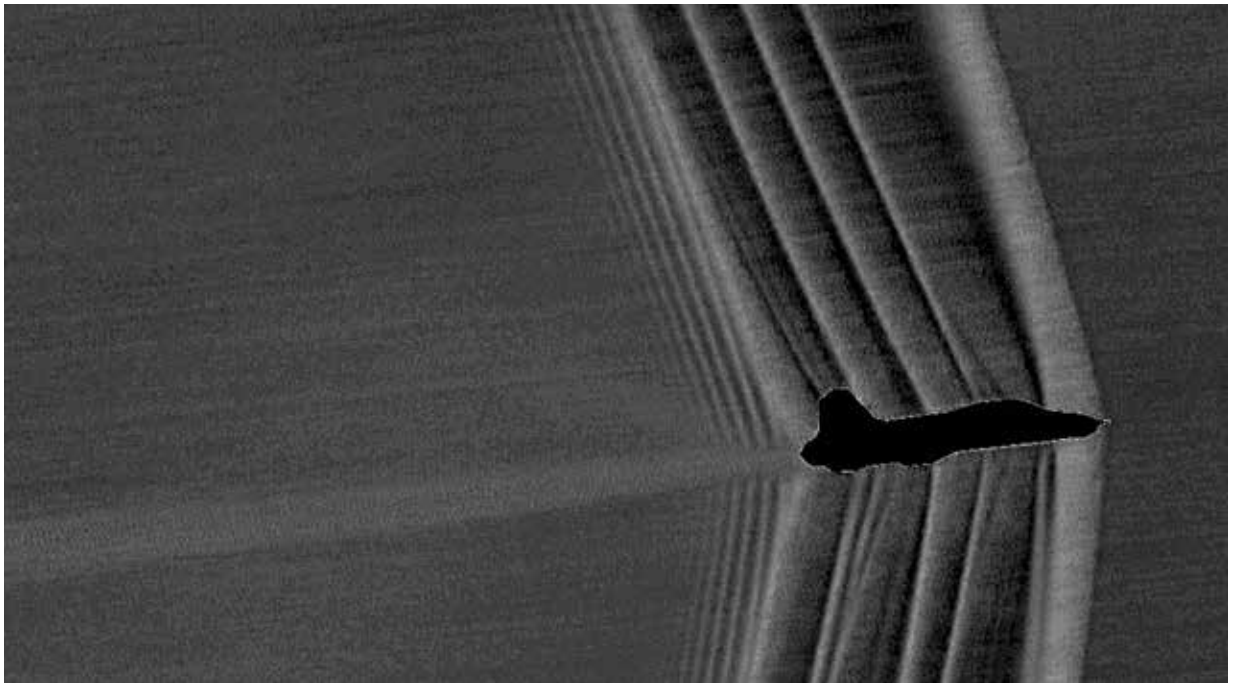
It's been more than 70 years since an airplane first broke the sound barrier, and yet supersonic flights remain mostly out of reach for civilian passengers, in large part because of the massive sonic boom that resonates when an aircraft hits supersonic speeds.

NASA wants to change that, and in 2016, the Agency announced an initiative called Quiet Supersonic Technology (QueSST) to build an experimental airplane that can break the sound barrier without rattling windows on the ground. Private industry is also intrigued by the possibility of quieter supersonic jets, and some of the software NASA has created for its work is proving quite useful to those companies as well.

Part of the complexity of designing an airplane is the way every decision impacts everything else, says aerospace engineer Michael Aftosmis, who works in the advanced supercomputing division at Ames Research Center. "You need to make sure that the engine is big enough to overcome the drag, so you need to know the drag before you can figure out how big an engine you need to put in. And if the engine is heavier you need more lift to carry that," he explains.

To see how a given design will perform, engineers can build models and test them in wind tunnels, but that is cumbersome and expensive. Early software to mimic wind tunnels, called computational fluid dynamics (CFD), was hailed as the way of the future, a virtual simulation that would replace physical testing.

However, that early software was, itself, time-consuming and expensive. The calculations were so intensive computers needed weeks or sometimes months to get an answer. And even before the calculations could be run, engineers had to prepare the computer model for simulation by mapping out a grid, called a mesh, around the vehicle. The process required not just tedious labor but also expertise—if it wasn't done well, the results would not be accurate. The more complicated the aircraft, the longer it took.



This photo, taken to help NASA engineers working on making sonic booms quieter, shows the air flow around an airplane as it surpasses the speed of sound—a visual representation of breaking the sound barrier.

Aftosmis came up with a way to automate the process so the computer created the mesh, no matter how complex, in seconds. His solution was to simplify the problem: instead of bending each cell around the shape of the airplane, resulting in a complicated array of differently shaped cells, Aftosmis and his team filled all the space with square cells. Where those cells came into contact with the aircraft, they clipped the bits that didn't fit.

"We went from a situation where every mesh was dependent on every geometry to a program that treats every mesh the same. Cells are either simple or complicated, and the complicated ones we just handle using algorithms from computer graphics," he explains.

Ames released the resulting software, Cart3D, in 2001, and Aftosmis says it added a new way for engineers to use CFD: "Rather than just doing one solution that you try to extract a lot of data from, it makes it very easy for the engineer to do many solutions from which they can extract trends and behavior."

The software is now used by every mission directorate at NASA, helping to simulate everything from the flight of the Space Launch System to what may happen as a meteor enters Earth's atmosphere.

Aftosmis and the QueSST team use it, too. "Right now the FAA doesn't allow supersonic transport over land, because it's too loud," says Aftosmis. "That's why you're still flying slow from Los Angeles to New York. To be able to change that we need to be able to fly supersonically more quietly. And that's exactly the project we're involved in with Cart3D."

> [NASA] is blazing a trail, and now, as that problem is becoming solved, they can hand it off to private industry."
>
> — Colin Johnson, Aerion Technologies

Because Cart3D is so fast, engineers can work backwards from the performance they want the plane to achieve. "For example, in the case of a sonic boom, we can come up with an acceptable pressure signature on the ground and reverse engineer the shape of the airplane that will give us that shape on the ground," Aftosmis says.

Technology Transfer

Although Cart3D made CFD easier and faster, it was still in many ways inaccessible for the broader commercial world of airplane designers. "The software is command-line driven, and it requires skill with UNIX and access to supercomputers," Aftosmis explains.

That changed, however, when Desktop Aeronautics acquired the license from Ames to distribute the package commercially. The company, which has since been acquired by Reno, Nevada-based Aerion Corporation and rebranded as Aerion Technologies, created a graphical user interface to help guide the designer through the process of using Cart3D.

Desktop Aeronautics was using Cart3D in its work designing a supersonic business jet for Aerion, explains Colin Johnson, now senior vice president for software development at Aerion Technologies. Seeing possibilities for the software to be used more widely in industry, Desktop Aeronautics sought and was awarded a Small Business Innovation Research (SBIR) contract to develop a plug-in, and as part of that process, it negotiated the commercial license for the whole software package (*Spinoff* 2012).

Desktop Aeronautics's contribution is key, Aftosmis says, because while NASA designed the software specifically to make CFD easier, the Agency wasn't in a good position to create the user-friendly interface commercial designers needed. Each interface needs to be redesigned for different operating systems, and once built, the software requires sustained maintenance.

"This is something that industry does remarkably well," Aftosmis says, "so it's a perfect partnership from that perspective."

Benefits

The commercial software, called GoCart, also integrates the additional applications the software requires, so you can just launch a single program and get full access to the data you need.

"Then it guides the user through in a logical way," Johnson explains. This is especially useful for intermittent users, because "if they walk away and don't come back for six months, then they may have forgotten the things they need to keep track of.

"We've actually packaged Cart3D to be user-friendly enough that students are able to work with it in their design projects at universities," he adds.

Aftosmis and his team also continue to work on increasing ease of use. Recently, they have been able to add a new parameter to allow engineers to specify how accurate an answer they need. "Then Cart3D can automatically mesh the geometry to meet their tolerance. We're trying to automate the solution process to remove any dependence on skill."

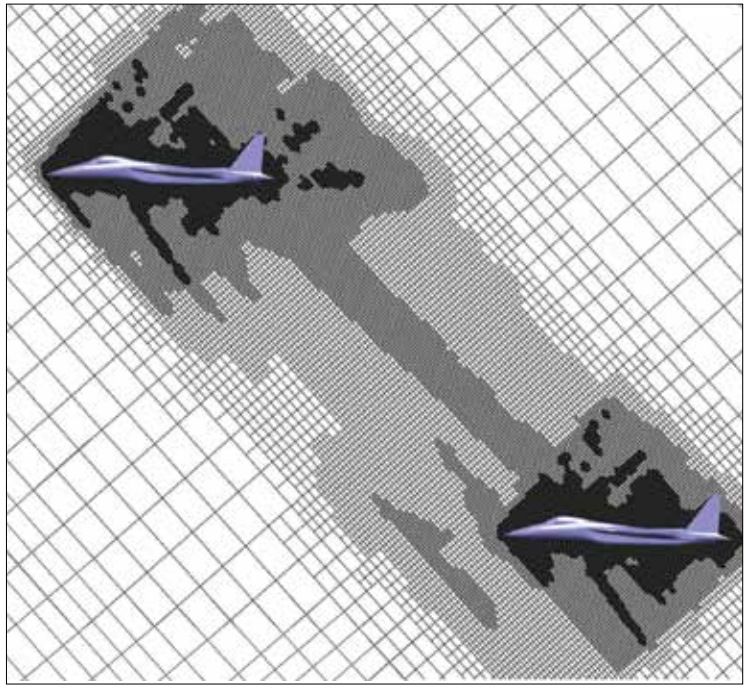
When Aerion acquired Desktop Aeronautics, it retained the commercial license for Cart3D and continued investing in the software. Current customers include commercial space companies in the United States, as well as major Government contractors and universities.

And Johnson sees potential to grow the business in a variety of ways, from offering a less expensive, stripped-down version for occasional users to expanding the capabilities beyond aviation.

Nevertheless, this sort of high-end software will never sell millions of copies, he notes, which is why the original NASA investment was so crucial.

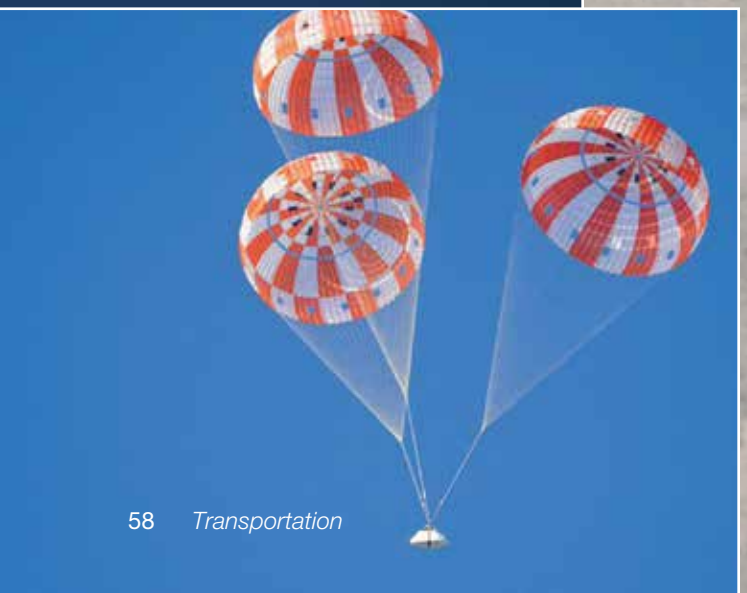
"There are things that need to exist, but it's difficult for the private sector to justify their creation. And that's typically where government steps in. Much of NASA's charter is essentially to do that. It is blazing a trail, and now, as that problem is becoming solved, they can hand it off to private industry," he says.

"NASA needed Cart3D, but there wasn't going to be any private company to build it. And now we're in this position to broaden the impact of that capability. But we wouldn't have gone into it had NASA not created the foundation in the first place." ❖



Cart3D automatically generates the mesh—the 3D grid—around the airplane, a process that had previously been complicated and time-consuming. The mesh, in this case around fighter jets flying in tandem at supersonic speed, helps the software run calculations about how the planes would perform in real life.

Orion Parachute Innovations Carry Commercial Rockets Back to Earth



NASA Technology

No human venture into space is a success until craft and crew have safely returned to Earth.

With their familiar orange and white stripes, the Orion capsule's three main parachutes hark back to the chutes that signaled the completion of each Apollo mission. There have, however, been updates to this crucial system since the early days of spaceflight, several of which have now found their way into the landing systems of some of today's commercial space companies. For example, while the Apollo parachutes were made entirely of nylon, Orion's suspension lines and risers—the structural grid that suspends the vehicle beneath the parachutes—are made of Kevlar, a material that has a much higher strength-to-weight ratio but wasn't invented until Apollo's final missions.

Other changes use more recent innovations. Rather than vent lines, which stretch across the vent at the top of a parachute and run the risk of tangling upon deployment, Orion's parachutes are crowned with a "vent hoop"—a solid ring of Kevlar that secures all the chutes' radials. This was an innovation Sandia National Laboratories came up with in 2001 while working with NASA on prototypes for the X-38 crew return vehicle, a project that was later dropped.

"It's a very elegant way of removing the risk of flailing of the vent and the tangling of lines," says Koki Machin, Johnson Space Center's chief engineer for Orion's parachute assembly system, who also worked on the X-38 Program.

Orion's parachutes deploy in stages. First, drogue chutes are deployed to stabilize and slow the spacecraft (background). After the drogues are cut loose (top), three tiny parachutes help pull the main chutes out of the capsule's forward bay. After the main parachutes are deployed, the reefing lines that hold them partially closed are cut one by one until they're fully open, carrying the craft to safety (bottom).

> "These commercial companies can't afford to spend the money to do that testing. It saved these companies millions and millions of dollars."
>
> — Koki Machin, Johnson Space Center

In 2006, after bringing on Airborne Systems, whose Space and Recovery Systems branch is located in Santa Ana, California, as a subcontractor to build the parachutes, Machin asked that the company also incorporate textile reefing loops. The main parachutes, as well as the drogue parachutes that deploy before them, fill with air in stages to slow the space capsule gradually, with reefing lines initially holding them partially closed. Traditionally, the reefing lines are secured with metal rings, but these can be crushed in the packing process, Machin says.

In other ways, the parachutes borrow heavily from Apollo's. "The layout of that drag surface is very similar to what Apollo did," Machin says. "In some respects, they're just a larger version of Apollo." The 13,000-pound Apollo capsule returned to Earth on three 84-foot-diameter parachutes, while Orion, at about 20,000 pounds, uses parachutes 116 feet across.

Technology Transfer

Another difference between the Apollo era and the present is that NASA is no longer the only player in American space exploration. Parachute system designs tested to Space Agency standards now find a ready market in the several companies developing their own spacefaring systems.

Airborne Systems has a long history of providing parachutes for NASA vehicles, from a Venus Pioneer probe launched in 1978 to the Space Shuttle's landing parabrake. Parachute systems the company is now supplying to commercial aerospace companies SpaceX, Boeing, and

Blue Origin all benefit from that background, but more specifically from work on Orion.

"We could take the lessons we learned from work we did for Orion and directly apply them to the SpaceX work," says Kurt Hempe, director of space and inflatables at Airborne Systems.

SpaceX uses parachutes that Airborne based on the Orion landing system to land its Dragon capsule, which has been flying supplies to the International Space Station (ISS) since 2012.

Boeing and Blue Origin have successfully tested parachute systems that incorporate aspects of Airborne's Orion work for their respective capsules. Boeing's CST-100 Starliner and SpaceX's Dragon 2 have been contracted to begin ferrying astronauts to the ISS as early as 2017 under NASA Commercial Crew Transportation Capability contracts. Blue Origin's New Shepard rocket and capsule have also received funding from NASA's Commercial Crew Development program.

Benefits

"NASA is able to afford all the development testing we're doing for the parachutes," Hempe says. "These commercial companies can't afford to spend the money to do that testing. It saved these companies millions and millions of dollars."

As spacecraft systems go, parachutes may seem relatively low-tech, but they are not among the cheapest to develop. This is because there is no way to test them in a lab. "We don't know how to model whether and how they will inflate—it's purely empirical," Machin says. "The test program is very expensive."

The parachutes, installed in a mockup of their spacecraft, have to be dropped from high altitudes to see what will happen. And with the lives of the crew on the line, this has to be done repeatedly. "You have to do extensive tests to characterize the behavior of parachutes," Machin says. "And you have to give them the opportunity to fail, and demonstrate where you might need design changes."

This likely means more than a dozen drops. It's why, even after Orion's first successful, unmanned test flight to and from space in 2014, NASA was still dropping models of the capsule the following summer —now with one main parachute and one drogue chute crippled—to make sure the system was failsafe.

One lesson the team learned from the tests, Machin says, was that the system's pyrotechnic reefing cutters were unreliable in their existing configuration. After the parachutes deploy, explosive cartridges in these cutters drive their blades through the reefing lines that hold the chutes partially closed, letting them open one stage at a time. Failure to cut a reefing line in either a drogue or main parachute would mean the chute would fail to fully open, which could easily lead to disaster.

Following cutter failures in the tests, engineers moved the devices' arming lanyards, changed the way they were armed, and added a sleeve to tightly control their direction, Machin says. "That also has become standard for what Airborne is doing for other customers."

In addition to improvements like cutter sleeves and textile reef line loops, Hempe says the video footage and data from repeated drop testing have helped the company compare seam and joint techniques, learn where the parachutes can benefit from reinforcement, and see where lighter materials can be used. "The name of the game in the space business is to make things as light as possible, but they also have to be as strong as possible," he says.

Machin says the work with Airborne presented an opportunity for NASA to push some of the lessons the Agency has learned and innovations it's made, such as advanced hardware and modeling capabilities, out into the market. "We were able to bring those to bear in the requirements for our parachutes," he says. "The companies might have gotten there eventually, but we were able to accelerate the process." ❖

Members of the Orion parachute team, the Exploration Flight Test 1 recovery team, and the U.S. Navy practice parachute recovery procedures in the Neutral Buoyancy Lab at Johnson Space Center. As part of the parachute team, Airborne Systems built the chutes to Johnson's specifications and has commercialized them for spacecraft companies.

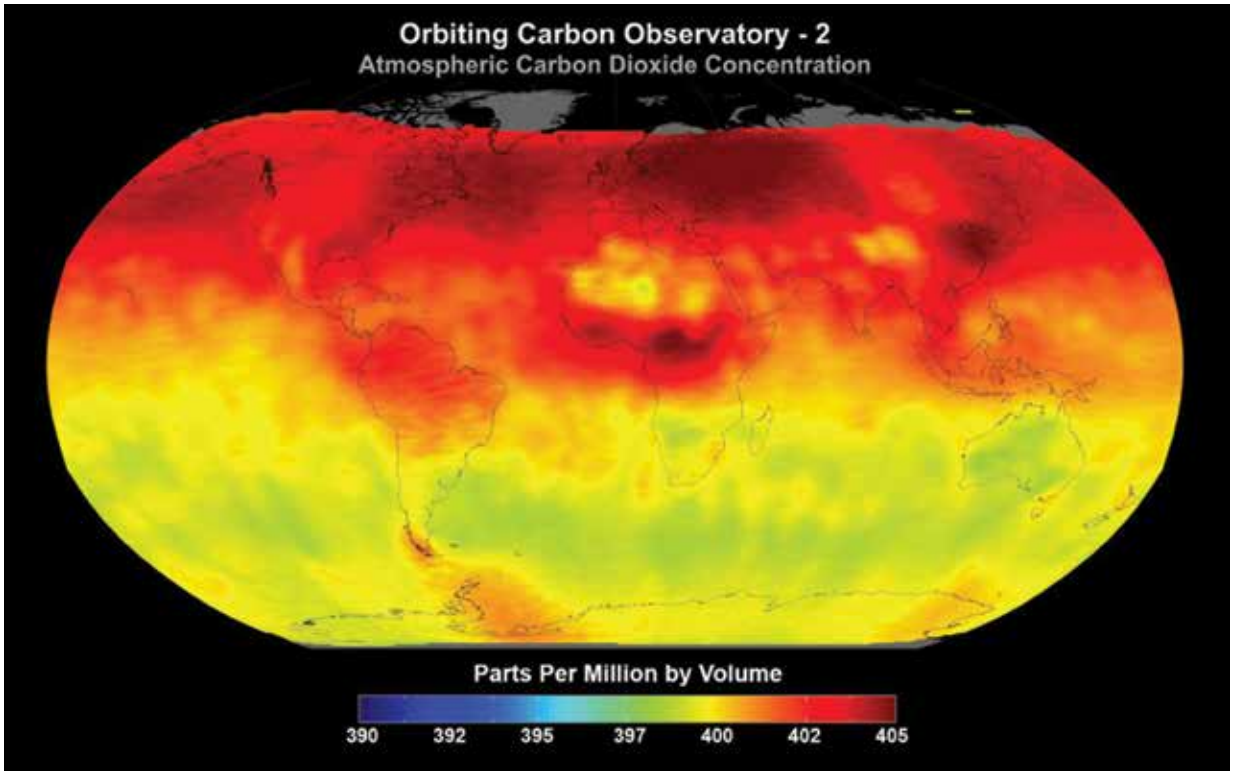
CO_2 Sensors Monitor Vehicle Emissions from Above

NASA Technology

Life on Earth is surrounded by, and dependent on, carbon dioxide (CO_2). Plants need it for photosynthesis; people and animals exhale it; industry and vehicles release it as a byproduct of combustion. The gas' role in climate change is clear to scientists, but another mystery remains—how CO_2 concentrates and dissipates in the atmosphere throughout the year, and when and why that happens.

Three NASA centers—Goddard Space Flight Center, the Jet Propulsion Laboratory (JPL), and Langley Research Center—are designing instruments to study this question from space. The project, a potential future satellite dubbed Active Sensing of CO_2 Emissions over Nights, Days, and Seasons, or ASCENDS, was named as one of 15 missions of critical importance for NASA in the 2007 Decadal Survey for Earth science by the National Research Council.

Langley's submission to the mission is an active remote sensor capable of taking CO_2 readings in darkness and during the day, explains Mike Obland, a research scientist in the Atmospheric Composition Branch of the Science Directorate at Langley. The sensor also allows for better measurement of CO_2 near the poles, where the sun's angle is low, and over the ocean when there's significant cloud cover.



NASA's Orbiting Carbon Observatory-2 satellite is helping scientists solve mysteries related to how carbon dioxide (CO_2) concentrates and dissipates in Earth's atmosphere seasonally. This map shows CO_2 concentrations in early 2016. Work on a similar instrument at Langley Research Center led to the development of commercial sensors used to monitor vehicle emissions remotely.

The sensor uses a trio of lasers that continuously beam through the atmosphere. "We scatter off a solid target, either a solid cloud deck or the ground," Obland says. The three lasers are set to slightly different wavelengths—one that is largely absorbed by CO_2 and two that are mostly scattered—and the tool measures the amount of light scattered back to gauge CO_2 concentration.

The Langley sensor uses a continuous laser while Goddard's submission relies on a pulsed laser. The continuous data can be compared to the pulsed data, as the readings from the three lasers are obtained simultaneously.

The proposed satellite hasn't yet been built, in part due to funding constraints, but the centers continue working on their potential contributions. The next Decadal Survey, in 2017, might reprioritize the satellite and encourage NASA to complete it, says Obland. On the other hand, he adds, given that multiple satellites launched since 2007 are now studying the carbon cycle from space—such as the Orbiting Carbon Observatory-2—the survey might instead recommend eliminating ASCENDS altogether.

Even if it never flies, the spirit of the project is sure to live on thanks to a Langley contractor who worked on the project from 2006-2009.

Technology Transfer

J. Stewart Hager worked as a NASA subcontractor at Langley through consulting firm Atmospheric and Environmental Research. One day during lunch, the company's ASCENDS team brainstormed alternative uses for the instrument on Earth.

"I thought: car exhaust," Hager says, noting that an estimated 40 percent of atmospheric CO_2 comes from burning fossil fuels. "It would save people a trip to the emissions testing station. You can just analyze the exhaust coming out of the back of the car from about five meters away."

Hager Environmental and Atmospheric Technologies' Emissions Detection and Reporting (EDAR) system has been purchased and installed by four states for various programs related to validating vehicle emissions compliance. In the future, EDAR could make drive-in emissions tests obsolete, replacing them with remote, laser-based sensors that can scan cars and trucks as they pass underneath.

Soon after, Hager left his contractor job in 2009 and founded Knoxville, Tennessee-based Hager Environmental and Atmospheric Technologies (HEAT) Inc., devising a monitor for CO_2 and other exhaust emissions based on the Langley ASCENDS tool. The company's Emissions Detection and Reporting (EDAR) system uses lasers to read CO_2, carbon monoxide, nitric oxide, and total hydrocarbons, along with individual hydrocarbons like methane, ethane, and ethylene.

Benefits

The technology contained within the EDAR system is a considerable advance over the machines at emission testing stations, Hager says. Like the Langley instrument, Hager's system uses lasers that are both reflected and absorbed by CO_2. Measuring the difference in the amount of each laser that returns to the EDAR provides the results from each vehicle. "We've improved the sensitivity and the reliability of remote sensing systems for car exhaust tremendously."

The EDAR system is a little slower than Langley's flight-qualified tool but also less expensive, and the results for on-the-ground tests are just as accurate. The system is installed on poles over high-traffic areas, where it monitors cars as they pass through.

Arizona, Connecticut, and Tennessee are the first states to deploy the EDAR systems. Agencies in those states are using the sensors "to audit the fleet of registered vehicles in cities where air quality does not meet the [Environmental Protection Agency's] emission standards in order to assess the effectiveness of their vehicle emission testing program," Hager says.

HEAT also has a research project underway with the California Air Resource Board, directed toward heavy-duty diesel trucks and evaporative emissions, such as gasoline vapors that escape from leaky gas tanks, loose hoses, or cracked pipes.

Some people drive around without emissions reducers in their exhaust pipes until it's time for their periodic test, Hager says. When that happens, the test results won't be an accurate representation of that vehicle's normal output. Real-world output depends on the driving habits of the vehicle's owner. There's also the possibility of vehicles overriding regular emissions testing systems, as was the case with some Volkswagen models in 2015. Having the EDAR system overhead all the time means each vehicle is tested, possibly without the driver's or manufacture's awareness," Hager adds.

The scan takes about a second and a half to complete, and each test results in a three-dimensional, multi-spectral image and a two-dimensional outline of the vehicle with its plume of emissions. Any interfering air molecules or pollution are identified and do not contaminate the results. "We know exactly if it's that vehicle the emissions are coming from because we scan over the entire width of the vehicle," Hager says.

If the technology were adopted nationally, Hager envisions that drivers whose cars pass emissions standards could receive a notification absolving them of having to come in for a test, while owners of out-of-compliance vehicles would have to be inspected.

While he understands the hesitancy on the part of government agencies to leave a known and trusted system in favor of new technology, he says the NASA origins of the system lend it credibility with potential clients. "NASA opened a lot of doors for me," says Hager. "The Agency spends a lot of money to make sure things are going to work the first time. When people learned I worked for NASA, they knew they had to take me seriously." ❖

Software Opens Computational Fluid Dynamics to the Uninitiated

NASA Technology

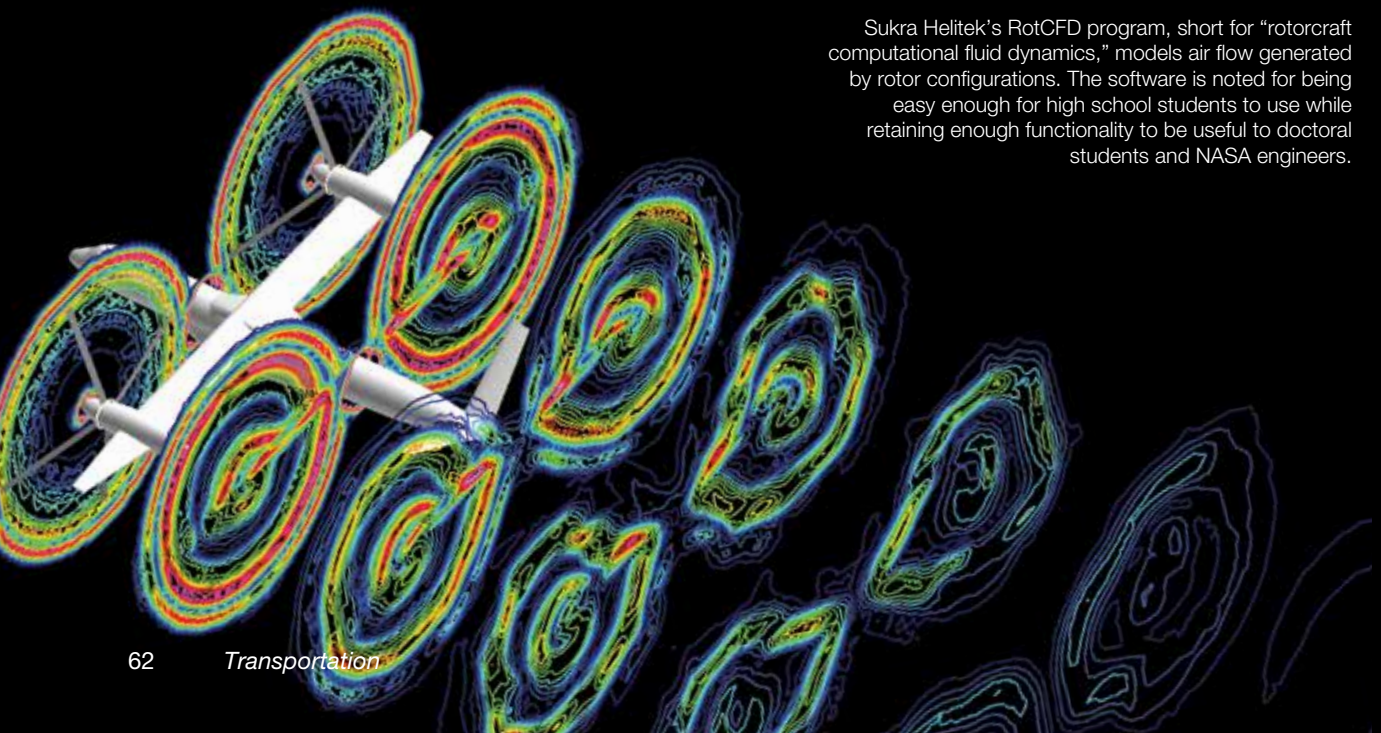
Sukra Helitek Inc.'s simplified, user-friendly computational fluid dynamics (CFD) software package began with Ganesh Rajagopalan essentially trying to work himself out of a job.

In the 1980s, the Iowa State University professor, who teaches courses on CFD, aerodynamics, and rotorcraft, among other subjects, frequently worked as a consultant for Boeing Rotor Systems—then called Boeing Helicopters—but the company often wanted help on projects too secret to bring in outside parties. "They asked, 'Could you develop software that will help us solve these problems so we won't have to involve you?'" Rajagopalan recalls.

He started work on such a program, founded his Ames, Iowa-based company in 1991, and landed a Small Business Innovation Research (SBIR) contract with NASA's Ames Research Center in 1999. By the following year, Boeing, Sikorsky, and Bell Helicopter were all using his Rot3DC program to model air flows generated by rotors. Under a series of SBIR contracts with Ames and the Department of Defense, Rajagopalan continued to build on the package, adding software modules, and two 2010 contracts with Ames finally resulted in the RotCFD—short for "rotorcraft CFD"—program that he hopes will one day be used not only in the industry but also in schools across the country.

"The main point is that this is a tool that everyone from high school kids on to NASA scientists can use," Rajagopalan says, noting that the program is comprehensive in terms of the depth and breadth of rotor CFD problem-solving it can do, but also easy to use and only as complicated as users need it to be for their purposes. "In one tool, NASA made it possible to bridge the gap from a very basic level to the very top level."

"At its core, it's an unstructured, unsteady Navier-Stokes computational fluid dynamics solver," says Larry Young, a research engineer who regularly uses the software in his work on novel aircraft concepts in Ames' Aeromechanics Office, noting that other such programs exist. What sets RotCFD apart, he says, are its user-friendly interface, its focus on rotorcraft, and its automation of some of the more complex and esoteric functions of CFD.



Sukra Helitek's RotCFD program, short for "rotorcraft computational fluid dynamics," models air flow generated by rotor configurations. The software is noted for being easy enough for high school students to use while retaining enough functionality to be useful to doctoral students and NASA engineers.

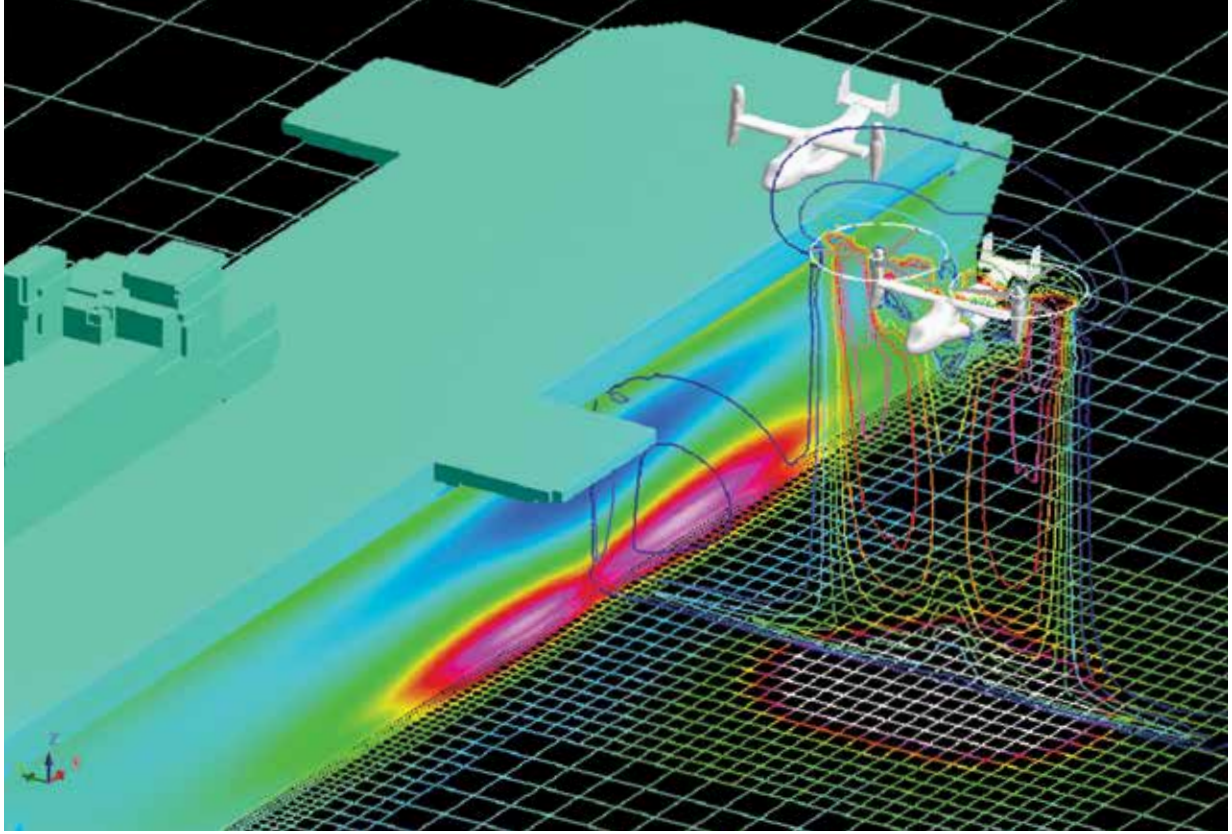
> "The main point is that this is a tool that everyone from high school kids on to NASA scientists can use."
>
> — Ganesh Rajagopalan, Sukra Helitek

For example, Young says, the program simplifies some of the higher-fidelity details of modeling, such as the flow near and about the rotor blades, to speed up the code while still producing reliable results. More importantly, it automates the generation of the grid that characterizes the air around the vehicle model.

In any CFD model, the air around the craft has to be broken up through a grid-generation process into tiny bins, called cells, whose ideal size and geometry depend on factors such as their proximity to the vehicle and the amount of force being modeled. In other professional programs, it's often a painstaking manual process. "A significant amount of a professional CFD analyst's time is taken up doing that," Young says, adding that most non-CFD engineers don't even know how to begin the task. With RotCFD, he says, "All you need to do is import a [computer-aided design] model into the code, or generate your own model, and then run the code, and it generates this grid for you."

Simplifications like these make the program ideal for novice analysts, as well as professional research and design engineers who, like Young, are not necessarily CFD experts, he says. "Progressively, over the last three years, we've been using it more and more, and it's become a fairly significant activity."

In addition to predicting the flow of air from a rotor—or multiple rotors—around a vehicle's body, the software can solve wake interaction problems, such as examining how the outwash from a rotor will interact with buildings



RotCFD is often used to model the ways that air flows from rotorcraft will interact with surrounding buildings and other objects, for example at airports.

and other structures at an airport, he says, noting, "You don't want to have too high a velocity blowing past people and things." It can also be used to model the airflow of propeller-driven airplanes and unmanned aerial vehicles, jet engine exhausts, and wind flows around buildings, and it has modules for additional capabilities, such as acoustic assessments.

Technology Transfer

"Without the SBIRs, there's no way I could have done something like this myself," Rajagopalan says, noting that NASA not only supplied financial support, but the Agency's engineers also provided input that played a significant role in shaping the final product.

Following the creation of RotCFD, Sukra Helitek won another Ames SBIR contract—its eighth—to further refine the program toward analyzing the ways that planes capable of vertical or short takeoff interact with their surroundings in an airport.

Rajagopalan still keeps four or five full-time employees as he continues to develop the product. In addition to major helicopter manufacturers and a number of NASA employees, he says, the Army uses the software for problem-solving, and he uses it in his teaching, working with college and high school students. Young has also used the program with a number of student interns at Ames over the last couple of years.

Benefits

Before he began using the product, Young would have to call upon CFD specialists to analyze any aircraft design he came up with. Now, he says, the software saves time and effort by letting him easily analyze his designs himself. "It allows freer rein in terms of innovation," Young says. "I can look at more concepts without having to draw in resources at the beginning."

The program is also capable of modeling complex, exotic configurations that might once have required a supercomputer, he adds. "Students can do some pretty powerful things with minimal ramp-up time. For student projects, that's really good for stretching their conceptual design skills."

He's already used the program for a paper he wrote on the operation of tilt-rotor vehicles at a vertiport, and he uses it for other purposes, such as predicting turbofan jet engine plumes on airport properties and supplementing wind-tunnel testing of rotors. His students have designed everything from "octocopters" to rotary-wing decelerators for a Venus probe using the software.

"I merely was looking for tools that could help me out to do a better job, and RotCFD is one of those we're now working with," Young says.

"Larry is one of my most sophisticated users who will use every function he can find in it," Rajagopalan says, noting that others may use it to delve deep into the science behind specific problems they're trying to solve.

He sees a broader market and a more interesting legacy, though, not in the industry but in the world of education, where the software could open what is still a fairly obscure discipline to a wider audience, introducing CFD to students as early as high school.

"You build the knowledge, and you provide the tool that they can use up to their PhD if they want to," Rajagopalan says. "Everything, really, is within the scope of this product." ❖

Hydraulic Carts Streamline Structural Tests for Aircraft

NASA Technology

Facilities for mechanical loads testing of aircraft and spacecraft are often jungles of cables, wiring, and hoses.

A typical structural loads test measures the strength and endurance of aircraft structures by applying mechanical forces to simulate the stresses of takeoff, flight, and landing. This is accomplished via a system of hydraulic actuators attached to the aircraft, each connected by a pair of hoses to a servo valve that controls the movement of the actuator and a load cell that measures the applied force. Dozens of surface gauges also measure strain at other locations on the vehicle. Each of these elements is normally wired to a control system. Given that a large test might use more than 200 actuators, all this amounts to miles of connections between the aircraft and the control system.

The Flight Loads Laboratory (FLL) at Armstrong Flight Research Center found a way to reduce the sheer volume of wiring and piping using a series of hydraulic carts that could each run multiple servo valves to multiple actuators independently, with just a single connection to the control room. The high bay where the team carries out testing also has a network of hydraulic piping beneath the floor, which the carts easily connect to wherever they are needed.

The Flight Loads Laboratory at Armstrong Flight Research Center (formerly Dryden Flight Research Center) tests the strength and endurance of aircraft structures, using hydraulic actuators to apply forces that simulate the stresses of takeoff, flight, and landing. The testing involves many cables, hoses, and wires, which the lab minimized by requesting a fleet of hydraulic carts that can be parked near the aircraft and connect to a front-end computer with just two wires. Two of the carts can be seen to the left rear of the plane above.

The problem that test engineers at Armstrong—then Dryden Flight Research Center—faced in the mid-2000s was maintaining and using an inefficient and outdated hydraulic system.

"Our old system was completely analog, very bulky, and not user friendly," says David Neufeld, the structural test systems specialist at the lab, noting that settings were changed with knobs and a screwdriver. "Each of the 48 channels had a cable bundle with hefty, multi-pin connectors running from the control room on the second floor to a panel in the corner of the high bay, and from there another section of cable ran to the test structure. All the bundles were semi-permanently installed. This made the system very inflexible and a mess to set up and tear down," he says.

"We wanted a mobile cart system with as few cables as possible. Our goal was to upgrade to a state-of-the-art digital system with the most flexibility our money could buy." The structural test team drew up specifications for a modular hydraulic control system and began seeking feedback from companies that could design and integrate it.

Technology Transfer

In 2006 the contract to build the FLL's next-generation hydraulic controller system ended up going to Moog Inc., a company that specializes in motion control systems and is headquartered in East Aurora, New York.

The company designed a multi-function mobile cart that not only houses the hydraulics for up to eight actuators but also includes most of the necessary electronics, which were previously housed in the control room. Each cart—known as a SmartCART—connects to the Real-Time Front-End (RTFE) computer Moog also built, which sits out of the way in the test area and can connect to up to 48 SmartCARTs. The servo valves and load-cell wires run from up to eight actuators to each cart, with just two wires—an Ethernet cable and a safety circuit cable—between each cart and the front-end computer. The RTFE is then wired to the command computer with a single Ethernet cable.

> “The main advantage is flexibility—the ease of setup and tear-down and minimal infrastructure to get a test laid out and installed.”
>
> — David Neufeld, Armstrong Flight Research Center

The lab ended up purchasing 10 carts and an RTFE, all of which it now relies on for its day-to-day operations. Engineers pull out only the carts required for the tests; the rest are stored away.

The setup is ideal for the FLL, which runs relatively short-term tests on a wide variety of aircraft and spacecraft, often testing multiple vehicles at once, says Art Benedict, aerospace test sales manager at Moog. “They don’t have to change anything between tests—they just roll the carts around.”

Neufeld says the facility can test everything from business jets to military aircraft, wing sections, and re-entry decelerators. An inert gas chamber with hundreds of heating elements, capable of achieving and controlling temperatures up to 3,000 °F on a full-sized prototype while applying hydraulic loading forces with the Moog system, allows the laboratory to simulate all stages of reentry and hypersonic flight.

Benefits

Benedict estimates the carts, which are now commercially available for any hydraulic structural testing facility, saved $350,000 in wiring costs compared to the previous system by reducing the cable quantity and associated infrastructure costs.

But Neufeld says the benefits go beyond wiring costs and even eliminating the annoyance, tripping hazard, and space constraints presented by a web of heavy cables and connectors. “For us, I’d say the main advantage is flexibility—the ease of setup and tear-down and minimal infrastructure to get a test laid out and installed,” he says, adding that this is also probably where the most money and time is saved.

Moog Inc. custom-built a set of 10 hydraulic carts to meet the needs of Armstrong Flight Research Center’s Flight Loads Laboratory, reducing the amount of cables and hoses in the lab, creating a more flexible setup, and bringing test operations into the digital age. The company now offers the carts, along with the accompanying Real-Time Front-End computer, for sale to commercial aircraft testing facilities.

“In a day or two, we can put a typical load test together, as far as the mechanical setup.”

And in the event of a cart failure, units can be swapped out and testing resumed in about an hour, he says, while a failed servo valve can be replaced in 10 minutes.

Benedict says Moog had nothing like the SmartCART before its work with NASA, and no one else seems to have come up with anything like it since. So far, the company’s found one commercial customer, a major helicopter manufacturer that purchased 10 units for a new testing facility. But this was no small sale, as the carts run around $250,000 apiece.

He says the price, partly a result of low-volume production, may be a barrier to some, and those who already have a facility wired may not see enough benefit to scrap their entire testing system. Meanwhile, facilities that do long-term lifetime fatigue tests may have less need to rapidly alter their setup. And the product’s uniqueness makes it impossible for a potential Government customer to put such a purchase out for competitive bid.

“The benefit would be mostly to people who want to be flexible in how they set this up and people who don’t have an existing lab,” Benedict says.

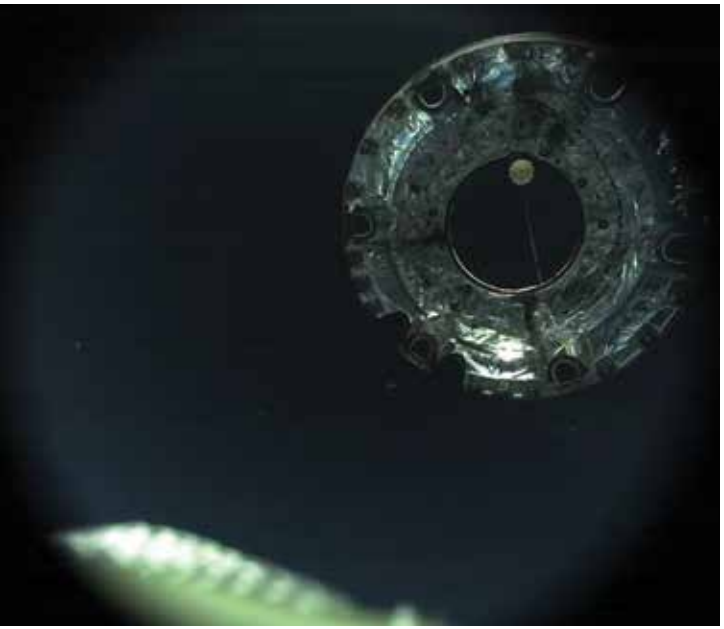
As old labs age and new ones are built, he says, the carts could catch on as a new model for hydraulic test facilities, which would also bring the price down.

“We’re quite happy with the system, and I know NASA’s happy with it,” Benedict says. “I’d say we may see more of this in the future.” ❖

Public Safety

The day-to-day environments NASA deals with are nothing if not extreme: the vacuum and wildly fluctuating temperatures of space, the fiery reentry into Earth's atmosphere, and the explosive rigors of rocket launches. The tools the Space Agency has created to navigate these harsh conditions often have applications on Earth, as you'll learn in this section. Earthquake dampers that stop buildings from shaking, high-speed cameras used in car crash safety testing, and vibration sensors monitoring railway lines are just a few examples of how NASA keeps people safe through public safety spinoffs.

Orion Video Requirement Advances High-Speed, Compact Cameras



Integrated Design Tools (IDT) built a compact, rugged camera with an unprecedented rate of memory storage to record parachute deployment during the Orion spacecraft's flight test in high-speed, high-resolution video. To capture the left image, showing the capsule's forward bay cover immediately after it was ejected, the camera had to adjust from total darkness to broad daylight within a few milliseconds. By the end of the deployment, the capsule's three main parachutes had released perfectly to deliver the craft safely to splashdown, with the process captured on film at rates up to 1,000 frames per second.

NASA Technology

Parachute deployment is usually a fairly simple—if crucial—operation. A small pilot parachute tossed into the wind might pull free a pin securing the main parachute container and then drag the larger chute out and into the airstream, where its lines release and it fills with air.

Little in spaceflight, though, is simple.

As the Orion spacecraft careened sidelong back to Earth during its first test flight in December 2014, a precisely coordinated series of events had to go off just as planned to slow the 21,000-pound vehicle from speeds around 350 mph at an altitude of 23,000 feet to just 20 mph by the time it plunked down into the Pacific Ocean four and a half minutes later.

After a set of parachutes and pyrotechnic piston thrusters removed the cover of the capsule's forward bay, mortars inside the bay fired a pair of drogue parachutes to slow and stabilize the craft's fall before they were cut loose to make way for the three 116-foot-wide main parachutes to be pulled free by pilot parachutes. The main chutes even filled in synchronized stages, as circles of line, called reefs, that held them partially closed were cut.

Everything went off without a hitch. We know this because the deployment also awakened a high-speed, high-resolution video camera within the forward bay that was custom-made to capture the entire sequence at speeds up to 1,000 frames per second. After all, if there was a snag, engineers needed to know precisely what went wrong and when.

In spaceflight, cameras aren't simple either. Not only did the engineers at Johnson Space Center and Lockheed Martin, who were designing and building the capsule, want a camera with higher-speed memory storage than any in existence at the time, but the device would also have to meet a host of other requirements.

"A camera with additional memory, controls, and environmental ruggedness, built in a sealed container that would

The Os V3 video camera takes advantage of some of the advances in high-speed, solid-state memory storage, as well as compactness and sturdiness, that the company had to make to meet the requirements for filming parachute deployment during the Orion spacecraft's first test flight.

“It's like having highways of **data with** very **wide lanes.”**

— Luiz Lourenco, Integrated Design Tools

One application for IDT’s highest-speed cameras is in automobile crash testing, where every millisecond must be immediately and permanently stored. The company’s cameras can be seen here mounted on both the car and the crash-test device.

withstand both the space vacuum and water immersion after landing, was required," says Vic Studer, video systems lead at Johnson. "The device also needed to be very small and lightweight and run on low power. No camera existed that could meet all these requirements."

Some came close, though. A company called Integrated Design Tools (IDT), located in Pasadena, California, specializes in cameras mainly aimed at the industrial and scientific markets, for uses like crash testing, which also requires rugged, high-speed cameras.

Technology Transfer

NASA and Lockheed Martin approached IDT with a request for a camera that would meet their stringent set of requirements.

"We had to come up with an elegant solution that was also cost-effective enough for the Government to accept it," says Luiz Lourenco, CEO of IDT, which ended up providing several cameras for the project through a subcontract with Lockheed Martin. "Our pride is that we were able to do it with very limited resources."

Most high-speed cameras are "what we call bricks," Lourenco says, meaning they're large and heavy, which runs counter to any space mission. Every pound it launches into space costs NASA about $10,000, and room aboard a capsule is extremely tight. So the company created an ultra-compact camera that fits in the palm of a hand.

The device had to survive not only the violence of liftoff and the saltwater of splashdown but also the radiation beyond Earth's protective atmosphere. There, radiation threatens what Lourenco calls "the soul of the electronics"—the memory chips and software, the computation model that will execute a series of commands, adjusting them according to feedback loops.

Such a sequence of commands might mean waking up and beginning to record at 1,000 frames per second, then slowing to 60 and speeding back up to 500 as events unfold, Lourenco explains. To preprogram this sequence of recordings, the company created what it calls "mission mode." The parameters—such as frame rates, durations, and shutter speeds—for up to 64 recording events are entered into an Excel spreadsheet, which is loaded into the camera to program a series of separate video shoots or a continuous recording at different speeds.

> "Some of this know-how already existed, but then you have to adapt it to these very stringent requirements. It's not a moneymaker, but it's a very good test bed for technology we want to incorporate into our products."
>
> — Luiz Lourenco, Integrated Design Tools

The camera also must automatically adjust for light exposure with each image it captures, even at hundreds of images per second.

The biggest challenge, though, was enabling the camera's computer to back up the data nearly as fast as it acquired it, storing each frame as it was recorded. Most high-speed imaging technology saves video to what's known as volatile memory, which loses all stored data when the power is cut. This would mean that if the camera aboard Orion experienced a broken cable or other glitch, all the parachute data from a very costly test run would be lost. The camera also needed all the video backed up before switching off for splashdown.

To permanently store hundreds of frames per second, the camera had to be able to transfer 10 to 12 gigabits per second to a hard drive, Lourenco says. "It's like having highways of data with very wide lanes."

Ken Barkman, the Lockheed Martin Communications and Tracking camera lead for Orion at NASA's Michoud Assembly Facility, says the camera lived up to expectations. One of the biggest challenges, he says, was capturing the forward bay cover as it was ejected from the capsule, letting light into the bay. "At 500 frames per second, the exposure algorithm adjusted the camera to the abrupt change in lighting from complete darkness to daylight within a few milliseconds," he says, adding that the high-speed "mortar events" that launched the drogue and pilot parachutes were also captured with high fidelity, as was the main parachute deployment at 400 frames per second.

"All of this video provided excellent support for the imagery analysis demonstrating that the features of the Orion vehicle performed as designed," says Ben Sellari, of Johnson's Vehicle Integration Office, who determined the initial requirements for image capture.

Benefits

"Some of this know-how already existed, but then you have to adapt it to these very stringent requirements," Lourenco says. "It's not a moneymaker, but it's a very good test bed for technology we want to incorporate into our products."

Some of these improvements have already been incorporated into IDT's product line. All of the Os series of cameras, in which the O stands for Orion, include the high-speed, solid-state memory the company developed for Orion.

In automobile testing—one of IDT's specialties—a car is typically outfitted with 8 to 16 cameras, and after a test, data is downloaded from each camera, one by one, explains Rick Sutherland, sales manager for IDT. "During that download, if anything happens to the camera or power source, you've lost all your data." In crash tests using members of the Os family, though, all the data from every camera is backed up within two seconds after impact.

In its testing, the Air Force films the deployment of weapons at high frame rates, and IDT's high-speed memory means planes in flight can fire test shots every two seconds or so, rather than circling and burning fuel while waiting for data to be backed up, Sutherland says, adding that the

Air Force has added a specification that these test cameras all include solid-state memory capability like IDT's.

Likewise, when broadcasters record at high frame rates for slow-motion sequences, the entire crew is left standing around while the video is stored before the next shot. "Our technology minimizes the cost of production, and they can shoot continuously," Sutherland says. He notes that the cameras also eliminate the need for a separate recorder for slow motion.

The cameras' light weight and small size are also advantages across industries. In crash testing, the vehicle has to weigh what it would on the road, so 16 heavy cameras would require other components to be removed from a vehicle. Even on a boom at a recording set, a lighter camera is easier to manage.

During recent military helicopter testing by IDT customer Boeing, Sutherland says, it was considered too dangerous for most personnel to approach the helicopter. Instead, test engineers were able to program three days' worth of recording using an Excel spreadsheet. "Even just that mission mode developed for Orion has paid off hugely," he says.

The cameras' ruggedness is another advantage that plays out across a range of applications. While it's an obvious necessity in crash testing, Sutherland says, "Even the movie guys, they're very hard on equipment. The ability to withstand a lot of G-force is an advantage to anybody."

Because the Orion camera had to survive not only splashdown but also a wide range of temperatures that can cause condensation and other problems, it also had to be completely sealed. The results are IDT cameras that can be submerged with no need for a waterproof housing, which Sutherland says has already piqued the interest of the Canadian Navy and is likely to get a lot more notice.

As more people and companies learn about the new capabilities stemming from IDT's Orion work, sales have continued to rise, he says. "The number we're selling is increasing, because we're getting them out and in front of people."

In fall of 2015, those technological advances culminated with the release of a camera that incorporates nearly all of them, the Os10 4K. ❖

The military uses IDT's high-speed cameras to film test-firing of weapons. The company's video cameras can store the massive data files immediately, eliminating down time between test shots.

Image courtesy of the U.S. Navy

Rocket Technology Stops Shaking in Its Tracks

NASA Technology

Rocket launches—or earthquakes—are already punishing experiences. But it turns out there are some things that can make them worse: like if the vibrations hit the structure you're in at just the right frequency to cause resonance, where the vibrations get bigger and bigger, in some cases up from bearable to all out disastrous.

But what if you could turn off that resonance with the flip of a switch? Engineers at NASA figured out how to do essentially that, and the device they created looks to have huge possibilities, from earthquake-proofing bridges to losing the sway in a skyscraper to shoring up an oil rig.

It all started when a team at Marshall Space Flight Center was working on the since-scrapped Ares I launch vehicle, which was set to send the Orion crew capsule into space for destinations including the Moon. The first stage of the launch was powered by a solid rocket booster, which, explains engineer Jeff Lindner, was creating an acoustic resonance.

"All structures have these natural vibrations. We call them modes," says Lindner, who worked for NASA for many years but worked on this project as a contractor. "Think of a tuning fork: hit it the right way and the sound resonates.

"When you get into trouble on a launch vehicle is when the resonant frequency of the engine lines up with the frequency of the vehicle structure. One is pushing at just the right frequency to drive the other. You have huge amplitudes—and stuff breaks."

In this case, the "stuff" could even be the crew sitting right above that rocket.

They had to find a way to interrupt that resonance, to stop the vibrations from amping up—typically a complicated and expensive thing to fix, because the frequencies are an integral function of the shape and mass of the structure.

One tried and true solution was something called a "tuned mass damper." First developed in the late 1800s, tuned mass dampers work by dissipating the energy of the vibrations into a secondary mass, perhaps attached by springs.

However, attaching a giant, heavy damper to a spacecraft was impractical, to say the least. So Lindner and the rest of the team began looking for a new solution. "We were throwing everything at the

The uncrewed Ares-1X launched in October 2009 on a successful test flight, but the rocket caused vibrations that would have been dangerous to humans on board. Engineers at Marshall Space Flight Center came up with a solution using the mass of hydrogen fuel in the second-stage rocket.

problem we could think of. Nothing was off the board," recalls project manager Rob Berry.

Wondering if they could repurpose something already on the spacecraft, Lindner and another engineer, John Townsend, came up with the idea of using the hydrogen fuel in the second-stage rocket: a huge liquid mass that was just sitting around waiting for its turn to get burned.

They tested the concept in the lab and it worked. But the result was not what they would expect from a tuned mass damper: "They were getting a knock-down on vibrations that was 50 to 100 times more than could be explained," Berry says.

The team began to realize that they hadn't designed a variation of a tuned mass damper—they'd come up with something fundamentally new. When they put their new device in the fuel tank and set the frequency, they expected to dissipate the force of the vibrations into the liquid, the way a classic tuned mass damper works. But instead, they realized they were actually causing the fluid to act as if it was no longer part of the spacecraft structure, which meant the resonance no longer occurred.

> "One small device, less than 100 pounds can knock out the resonant response of a 650,000-pound vehicle. What else can we do?"
>
> — Rob Berry, Marshall Space Flight Center

"We realized we're messing with the fundamental dynamics of the system. We're not dissipating energy—we have the ability to change the system dynamics before it could ever occur," says Berry.

They called the device a disruptive tuned mass damper. Berry likens it to a balloon that expands and contracts at a specified frequency. When it contracts, it creates space, which the liquid flows to fill.

"What that means is that little bit of expansion and contraction starts involving a whole bunch of fluid," Berry says. Now, instead of moving with the vibrations of the structure, that fluid is moving with the contractions of the device. So where before the fluid acted as part of the structure of the rocket, helping govern the frequency it vibrates at—the way more or less water in a glass changes the pitch when you run a finger around the rim—now the fluid is doing its own thing, and the structure will no longer resonate at the same frequency.

"We started thinking, this is great, look what we just did: one small device, less than 100 pounds can knock out the resonant response of a 650,000-pound vehicle. What else can we do?"

Engineers Rob Berry and Jeff Lindner work on pipes that will contain the disruptive tuned mass device they first helped create for the Ares 1 program. Now they are adapting it for future NASA use and for commercial use, such as in buildings, bridges, or oil rigs.

Technology Transfer

By now, the Ares I vehicle had been cancelled. But Berry, Lindner, and the team knew they were onto something that could have huge implications not just for NASA but for private industry as well, and they didn't want to let the project die.

They began adapting their device to a new setting, an unused building at Marshall that happened to be about as tall as a launch vehicle. The idea was to be ready for whatever vibration problem NASA had next—but they also began looking for users outside the Agency.

Engineering firm Thornton Tomasetti has licensed the disruptive tuned mass damper technology for commercial use in buildings and bridges. Here a crane lifts a damper to the roof of B2 BKLYN, the first project they are using the NASA-derived technology on.

"Think about helicopters, bridges, buildings, anything that has a big vibration problem. We now had a new tool to knock out those issues," says Lindner.

By sheer coincidence, through a conversation at a party, someone at engineering and design firm Thornton Tomasetti heard about the device, and the company was immediately interested. It sent a team to learn more.

Elisabeth Malsch, vice president at the New York City-based firm, recalls walking into the building at Marshall where engineers had used two hydraulic shakers to get the building moving and calmed it with their device, this time housed in a long PVC pipe filled with water.

Then Berry told her to turn off the disruptive tuned mass device.

"It really does feel magical," she says. "You flip the switch. There's no sounds you hear. The building movement just starts to take over."

The Thornton Tomasetti team was convinced: this was worth exploring for their own projects. They obtained a research license to test the technology further and then entered a Space Act Agreement to confirm more details of how the device would work on their structures.

Satisfied with the results, they negotiated a license agreement for the exclusive rights to use NASA's patent on bridges and buildings and began making plans to install it for the first time on a new building in Brooklyn.

Benefits

B2 BKLYN is not particularly tall, but it's extremely light, which means when there's a lot of wind, the whole structure would sway back and forth in a way that's very uncomfortable for the people inside.

The Thornton Tomasetti team knew they would need some kind of damper, and the NASA one beat the other options on a lot of levels, Malsch explains.

"The fact that this system is lighter and uses conventional piping means it's cheaper than what they were going to use in unit price and also easier to get on the building," she says. "And because we can use conventional parts, that allowed for later design changes than one can usually accommodate."

The competing systems under consideration either house water in a huge concrete vat, specially designed to match

the building's frequency, or attach a huge mass with springs and cables. Both are expensive, extremely heavy, take up a lot of building space, and are hard to modify once they're built. "But with the NASA system, a person could tune it within a day, with conventional tools," Malsch says.

The firm is waiting to see how it performs in Brooklyn before committing to more projects. However, Malsch says, "We've certainly had interested parties, and there's a lot of interest in this working well." It has begun marketing the system on the company website under the name Fluid Harmonic Dampers.

Berry says he thinks there is every reason to believe this new technology will become standard across multiple industries as people become aware of it and what it can do.

The NASA-developed devices are installed in four specially designed water-filled pipes along the roof of B2 BKLYN. The damper, which Thornton Tomasetti is marketing as Fluid Harmonic Dampers, is cheaper and more flexible than previous vibration dampening options.

> "Think about helicopters, bridges, buildings, anything that has a big vibration problem. We now had a new tool to knock out those issues."
>
> — Jeff Lindner, Linc Research

"You can put it in an ocean liner, with a ballast tank. Or in a building with a swimming pool," he says, and notes that the approach is not limited to fluid systems but could also work by leveraging mechanical masses.

Besides the benefits Malsch listed, he says the NASA-designed dampers work more quickly than traditional tuned mass dampers, which require time for energy to be transferred and dissipated. "But by changing the fundamental attributes instead, it is no longer the same system—and this occurs at time equal zero."

In addition, traditional systems have to be tuned to either high or low frequencies, which means they might mitigate the high frequencies of an earthquake event but would do nothing to mitigate the lower frequency vibrations from a wind storm. This new device can do both.

The damper has already won a slew of awards for its inventors, including NASA's Exceptional Engineering Achievement Medal. The Marshall team members have also gotten around a dozen patents related to the innovative technology.

"This is a clear paradigm shift versus what we've been taught. Tuned mass dampers are so entrenched in our thinking," Berry says. "It's hard for people to give up a century's worth of thinking. But we've made that century's worth of thinking obsolete." ❖

Micromachined Sensors Monitor Train Rails, Predict Failures

NASA Technology

Sensors originally designed to predict failures in a helicopter transmission have found an unexpected use detecting problems in train tracks. When Ridgetop Group created its RotoSense rotational vibration sensor under Small Business Innovation Research (SBIR) contracts with NASA's Glenn Research Center, the company envisioned applications not just in helicopters but also in automobile transmissions, industrial equipment, and oil and gas drilling. But train axles, too, rotate at a high rate of speed and can indicate anomalies by vibrating irregularly.

"From our perspective, it's a very promising application of the sensor," says Andwrew Levy, Ridgetop's vice president of marketing.

The technology began with NASA's Subsonic Rotary Wing Project, which is working to ensure the competitiveness of the U.S. helicopter industry and meet Department of Defense requirements, with goals like higher efficiency, less noise, and means to assess and predict the health of components. It was with that last objective in mind that Glenn granted SBIR work to the Tucson, Arizona-based company.

"The goal was to develop a wireless accelerometer that could be installed on a rotating gear in a helicopter transmission to monitor its health and condition," says Dave Lewicki, who ran Glenn's Helicopter Transmission Test Stand when the work was being carried out and oversaw both SBIR contracts. Normally, sensors would be placed on the outside of the transmission housing, whereas the microelectromechanical systems (MEMS)-based accelerometers Ridgetop came up with were to be attached directly to components inside the transmission, which is not a friendly environment.

"If you're rotating at thousands of RPMs, first of all, you need to package the thing so it doesn't fly apart," Levy says, adding that the devices also need to withstand exposure to oil and high heat.

But there were more challenges to overcome than ensuring durability. Each sensor is "basically three MEMS-based accelerometers measuring G-force in three directions," Levy explains. For a device to pick out variations in vibration while sitting on a component that's whirling frantically inside a rattling motor or transmission, it needs not only exquisite sensitivity but also complex, fine-tuned software. The sensors transmit raw data wirelessly to an outside unit, where all the noise is filtered out to obtain a meaningful vibration signature and, ultimately, what Levy calls "actionable maintenance data."

Ridgetop Group adapted its RotoSense microelectromechanical systems-based accelerometers, originally developed to monitor components of helicopter transmissions, repackaging the hardware for use in detecting potentially dangerous anomalies in train tracks.

Technology Transfer

Ridgetop delivered two prototype sensors for testing in the transmission of a Bell OH-58 Kiowa helicopter. The first test showed that Ridgetop's MEMS sensor, mounted on a gear inside the transmission, performed at least as well as traditional sensors attached to the outside housing. Lewicki says he considered this a success, noting that he didn't expect external sensors to have difficulty monitoring a gear so close to the outside of the device.

"We were happy the MEMS sensors performed as well as the traditional ones, thus validating the concept," Lewicki says. "The proposed real benefit of the MEMS sensors are situations where the fault components are buried deeper inside the transmission, such as a planetary system." Lewicki retired before that test could be carried out, but Glenn still plans to complete that project.

In the meantime, Ridgetop took its NASA-validated sensing system and began partnering with companies to develop a final commercial product (*Spinoff* 2012).

The company marketed its sensors under the name RotoSense, with the hub that communicates with the sensors dubbed Sentinel Gateway. The RotoSense Data Conditioner prepares data from the sensors for processing with the company's patented Adaptive Remaining Useful Life Estimator (ARULE) software, and the whole product line is known as Sentinel Motion.

The company set out to find other applications for its creation in a world where technology is full of spinning parts.

For example, a rolling train axle is, mechanically, little different from the axles in any other vehicle, but an automobile can go more or less wherever its driver likes, while a train is bound to the same track on every pass. And while a pothole in the road is an annoyance, an anomaly in a train track can mean disaster. So the company hit on the idea of monitoring vibrations in train axles to detect and locate problems with the rails they roll on.

The sensors had to be repackaged to sit on each end of a train axle, right above the meeting of wheel and rail for maximum sensitivity. The basic algorithms for noise elimination remain unchanged, but programming to identify the significance of any anomalies had to be rewritten specifically for rail.

Calling the retooled system RailSafe, Ridgetop took it out to the Federal Railway Administration's Transportation Technology Center in Pueblo, Colorado for testing.

Benefits

The first step to testing or using RailSafe is to map the section of rail being monitored, including any junctions, bridges, and other irregularities that the sensors might pick up on. "There are a lot of features in the track that, if you don't know what you're rolling over, you don't know if it's something expected or something bad," Levy says. "You need to know what's there, where they are, and have a map and a visualization tool to alert you as to what was seen and whether it requires action."

When Ridgetop engineers arrived in Pueblo, he says, the facility's operators told the company that others, too, had tried putting some kind of sensors on train wheels or axles, and the devices normally didn't last. "Well, ours did," Levy says.

Over the course of four nights, four sensors—two on a rail car and two on a locomotive—rolled 400 times around the facility's 2.7-mile loop. "The people who run these things got progressively more excited about what we were doing," Levy says. "Even to the old pros at the test track, this is something new."

Having analyzed the test results, he says, "We're starting to get a very clear picture of what the sensors picked up and what was on the track."

Next, the company plans to train the technology to look for any anomalies in a train's wheels. It's planned to ultimately be able to perform prognostic reasoning for both wheels and rail, predicting their lifetime and warning of possible failures before they occur by monitoring long-term changes in vibration.

Just the ability to detect a problem in a rail can avert catastrophe, but prognostic capability for wheels and rail would not only go further toward preventing accidents but also save the cost of unnecessary preventive maintenance. Levy points out that the sensors can also perform the simpler task of ensuring that certain standards are met, such as limits on G-forces resulting from cars being coupled.

Ridgetop's analytical tools can also be used with sensors other than its own.

Ridgetop launched RailSafe in mid-2015 as a kit containing the necessary sensors, data collection hub, and software packages to outfit and monitor trains. To help customers ensure the system meets their needs, the company also offers installation and training services. Levy says the hardware and software appear to be unlike anything else on the market. "Based on the excited reaction of people we talk to about this technology, we get confirmation of that."

Meanwhile, the company is exploring applications in wind and water turbines, as well as factory floor machinery.

For his part, Lewicki remains optimistic. "Our hopes are that the embedded MEMS sensors will perform better since they are installed directly on the faulty component," he says. NASA's eventual validation of Ridgetop's planetary gear sensor will likely speed that success. ❖

"Even to the **old pros** at **the test track,** this is something **new."**

— Andrew Levy, Ridgetop Group

Ridgetop Group's RailSafe sensor fits on the ends of a train's axles, where it monitors for vibrations caused when the wheels roll over anomalies in the rails.

Wire Sensors Alert to Dangerous Conditions in the Clouds

NASA Technology

One common hazard facing airplanes is ice: not just on the ground, but in the air, where it can coat wings or engines. But how do you know when icing conditions exist up in the clouds? NASA has been working for years to build better models, and the tools it's helped develop as a result are turning out to be useful well beyond passenger planes.

One of the best ways to determine how much supercooled liquid water—the culprit behind airborne icing—is lurking in the skies is by sending up a sophisticated sensor on a specially-equipped research aircraft, explains Michael King, an aerospace engineer at the Icing Branch of NASA's Glenn Research Center. However, although the probes work extremely well for research, instrumented aircraft are not flown day-to-day to provide real-time icing hazard information, which is what pilots and operators could use to improve flight safety.

Enter NASA's ground-based Icing Remote Sensing System (NIRSS), which could potentially fill that gap. It uses a vertically pointing Ka-band radar, which measures the size of water drops in the air; a lidar ceilometer, which uses laser pulses to measure cloud base height; and a radiometer, which measures temperature at different altitudes and integrated liquid water.

"Using the information from those three instruments, you can infer what the icing hazard is at any given time," King explains.

In order to prove the system works, the developers need to compare the NIRSS prediction with what's happening in the air. NASA knew it could do this with instrumented aircraft, but they are expensive—all told, King says, a winter flight campaign could cost hundreds of thousands of dollars

So in the early 2000s, NASA put out a call for something new to act as a backup and a way to gather preliminary data: a lightweight, inexpensive sensor that could be sent into the clouds on weather balloons. John Bognar, an atmospheric chemist with an affinity for lightweight instruments, thought he could make something work.

Glenn Research Center icing expert Michael King (left) prepares to launch a weather balloon equipped with a supercooled liquid water sensor designed by Anasphere Inc. Results from balloon launches such as this one will help verify whether a ground-based NASA system can effectively predict icing conditions aloft.

Technology Transfer

Bognar is the founder of Bozeman, Montana-based Anasphere Inc. He had previously built lightweight meteorological instruments to help get chemical measurements for his research and set about using the same principles to build the sensor NASA needed.

"When I saw NASA was interested in icing conditions, I looked at what people had done before. That's where I usually start. I found a previous designer had developed this vibrating wire sensor for atmospheric soundings in the 1980s," he explains.

As the sensor rises through the atmosphere, it encounters supercooled liquid water, which freezes onto the wire sensor. That accumulating ice causes the wire vibrations to change, and the sensor registers those changes and reports it back to the ground station. By analyzing that information, scientists can determine the content of supercooled liquid water.

It worked well, but when Bognar looked closer, "I said, my goodness, this sounds really heavy." While the original sensor called for electromagnets and magnetic coils to produce and measure the vibrations, Bognar turned instead

Ice poses a significant hazard to planes in the air, where it can accumulate on wings and engines. NASA is studying ways to better predict when icing conditions are particularly dangerous, and one tool it is using to test its research, a lightweight, inexpensive sensor, is proving useful outside the Agency as well.

to piezoelectric elements, which can convert physical movement or pressure into electricity—and vice versa.

Bognar hoped to use small piezoelectric elements to both make the wire vibrate and detect the vibrations. Approaching NASA with the idea, he was awarded a Phase I Small Business Innovation Research (SBIR) contract to develop it.

"The vibration detection part really ended up being pretty straightforward," Bognar recalls. "Once I was working with these little lightweight piezoelectric sensors, it was clear this was the right choice."

The piezoelectric transducer didn't work as well to create the vibration, but Bognar was able to use a mechanical actuator to pluck the wire instead. "It ended up being simple and robust and effective, even though we lost one degree of the elegance of the solution," the scientist recalls.

Benefits

NASA was so pleased with the resulting product that it offered Anasphere a second, Phase III SBIR contract to produce the sensor for its weather balloon studies. "The sensors are lightweight and don't require a lot of power, so they're ideal for working on a balloon," King says. "This tool will allow us to improve our ability to predict those conditions and inform the community when there are those hazardous conditions aloft."

Outside of NASA, the Department of Energy (DOE) is also using the vibrating wire sensors in its studies of cloud formation in the lower levels of the Arctic atmosphere. The DOE is working to understand the effects of clouds on climate: how they reflect and absorb heat energy and how that impacts the radiation balance on Earth.

"The niche that we fill is that we have a much more inexpensive sensor," explains Bognar. "When you're using the big expensive sensors, you will have one sensor. If you wish to develop a vertical profile, you have to winch your sensor up and down. So when you're looking at one point, you're missing what's happening above and below."

"The advantage of our sensor is you're able to deploy multiple sensors all at once and see upper and lower altitudes simultaneously to see how the cloud is evolving."

The DOE also uses another product Anasphere sells called tethersondes—instead of floating away, the devices are attached to long lines that can be reeled back in. The supercooled liquid water sensors are sold as a separate add-on to the tethersonde package.

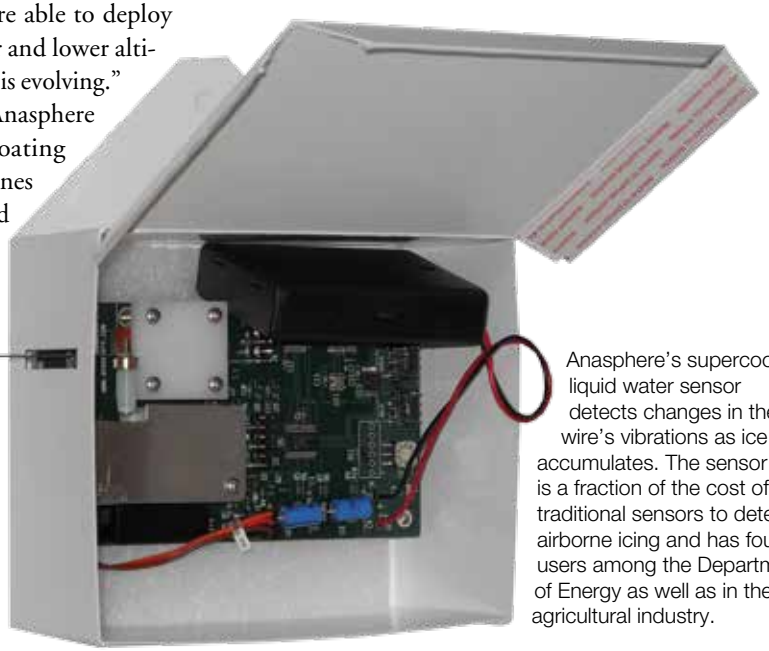
Anasphere's vibrating wire sensors are also starting to find a new market in China, Bognar says, where a Chinese affiliate of German radiosonde company GRAW is expected to market them to farmers. The sensors can sound a warning when icing conditions near the ground show signs of danger for crops, such as when a very cold fog gathers.

The vibrating wire sensors are not a huge portion of Anasphere's revenue—almost by definition, since they were designed to NASA specs that they be disposable and as inexpensive as possible, leaving little in the way of a profit margin. However, among the small, inexpensive instruments Anasphere makes, Bognar says the supercooled liquid water sensor has been a success.

And, he says, without NASA he doubts he would ever have even delved into building the sensor. For one, the profit margins were always going to be low, so without the NASA investment, it may not have made financial sense for Anasphere to dedicate its resources to the project. But also, the relationship with NASA helped Anasphere make connections around the icing community.

The NASA project director at the time, Andy Reehorst, "helped build awareness of the sensor, which helped lay the market for it. Without that kind of support, we would have been trying to find a way into the icing community, and the odds of success would have greatly gone down," Bognar says.

"That's a big part of where NASA's involvement was so critical to making the whole development path successful." ❖



Anasphere's supercooled liquid water sensor detects changes in the wire's vibrations as ice accumulates. The sensor is a fraction of the cost of traditional sensors to detect airborne icing and has found users among the Department of Energy as well as in the agricultural industry.

Fast-Flow Nanofiber Filters Purify Water at Home and in the Field

NASA Technology

More than a billion people around the world lack easy access to clean water—some trek for miles just to fill jugs for themselves and their families. Even where the liquid is in abundance, it is often contaminated with viruses or bacteria that can cause deadly diseases, especially in vulnerable young children.

In developed countries, too, water sources are occasionally contaminated or cut off altogether following natural disasters, resource mismanagement, or an intentional attack.

And there's another group that lacks access to abundant, safe, clean drinking water: astronauts. In space, they have to take what they need with them and reuse and recycle every precious drop. On the International Space Station, where U.S. Astronaut Scott Kelly recently spent a year in orbit, specialized technology developed by NASA collects every bit of moisture, including sweat and urine, and turns it into drinkable water.

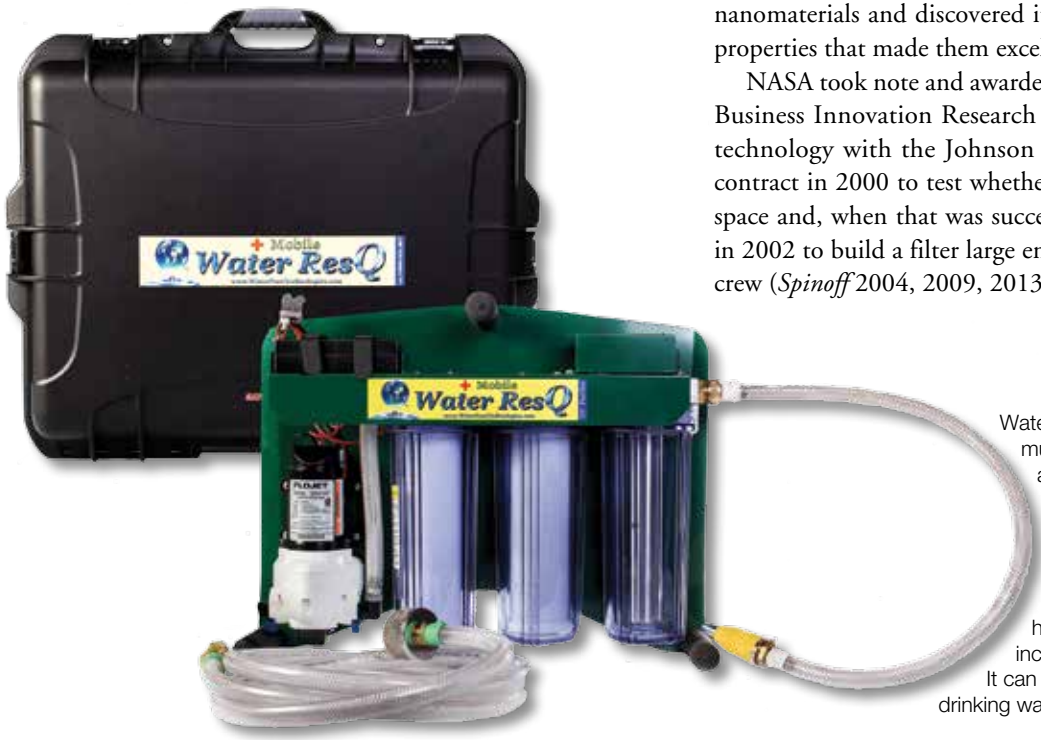
The solution in all cases is filtration. But not all filters are created equal: many of the inexpensive ones can siphon out dirt and low-level contaminants, but they can't do anything for many of the more dangerous infiltrators, especially viruses. Many bacteria and single-celled organisms also pass through filters, and the filter itself can even become infected with these microbes, passing them on to previously uninfected water.

With plans in place for ever more distant human space missions, NASA has used its resources to help come up with some of the best water-filtering technology available.

Technology Transfer

In 2000, Florida-based Argonide was working with nanomaterials and discovered its NanoCeram fibers had properties that made them excellent as water filters.

NASA took note and awarded the company two Small Business Innovation Research contracts to develop the technology with the Johnson Space Center: a Phase I contract in 2000 to test whether it could purify water in space and, when that was successful, a Phase II contract in 2002 to build a filter large enough to serve a full space crew (*Spinoff* 2004, 2009, 2013).



Water Pure Technologies builds multi-level filtration systems in a variety of configurations—installed and portable, battery-operated and hand-cranked. The Water ResQ U.V. system operates with a 12 volt battery and has four stages of filtration, including the NanoCeram filter. It can produce 174 gallons of safe drinking water per hour.

The main benefit to the nanofibers was their unusually strong "bioadhesivity"—meaning particles, including viruses and bacteria, were easily attracted to the fibers. When water passed through a filter woven of the fibers, these particles flocked to the fibers and got stuck there, leaving virus- and bacteria-free water on the other side.

"The NanoCeram fibers produce an electropositive charge when water flows through them. Many impurities carry a slight negative charge and are absorbed by the filter," explains Tom Smokoff, founder of Water Pure Technologies.

Other filters designed to block viruses and bacteria use membranes with pores so small only water molecules can get through. Dangerous contaminants, like viruses and bacteria, are too big to pass.

However, the process can be painfully slow, especially when large quantities of water are needed. The woven nanofibers have bigger pores—up to two microns—allowing water to pass through at a much faster rate, while still eliminating better than 99.9 percent of viruses and bacteria, outperforming other filters on the market without using chemicals.

These attributes were what drew Smokoff to the filter when he began designing filtration systems for emergency workers, backpackers, and communities in developing countries, among others.

He contacted Argonide, learned that other companies were licensed to produce the filter for sale, and shopped around to find the best source for NanoCeram filters to his specifications.

Benefits

Water Pure Technologies, based in Murray, Utah, offers a range of Water ResQ systems: both fixed, whole-house or under-sink products and portable, battery-operated or hand-cranked systems that can be packed up and brought to a water source.

"We're building these pieces so they can do a lot of water at a very low cost. My whole goal is to bring clean water to

> “These filters enable us to design and build systems that are able to really make a difference for whole communities.”
>
> — Tom Smokoff, Water Pure Technologies

humanity at an affordable price,” says Smokoff, who has worked with humanitarian groups on and off for two decades. For instance, Water Pure Technology’s Mobile Water ResQ U.V. units fit in a suitcase, have a small battery that can be recharged with a solar panel, cost around $1,400, and filter 2.9 gallons of water a minute. “We’re outperforming mobile units that are 10 times the cost.”

The systems combine multiple filters in a series. A first-level strainer filters out dirt and large particles, “like a sock filter,” he says. Then, as the water is pulled through the pump, it goes through a coconut-carbon filter to eliminate many other contaminants. Next, it reaches the most expensive—and most sensitive—filter: the nanoceramic filter, which eliminates everything left, including viruses. And after the three-stage filtration process is completed, the water goes through an ultraviolet chamber for added protection.

In areas where water contamination is especially high, Water Pure can add up to two additional stages of filtration. “All of our systems remove lead, chlorine, E. Coli, coliform bacteria, viruses, algae, pharmaceuticals, foul tastes and odors, and many other contaminants,” Smokoff says.

The multiple stages act as a fail-safe, if any of the filters fails. They also protect the NanoCeram filter, so it doesn’t get clogged with dirt or other larger-scale contaminants.

“What we’re trying to do is make that NanoCeram filter last longer, because we’re working with groups in the field that are going to rely on that to remove viruses. And if I can make that filter last four or five times longer, for humanitarian groups that’s a huge plus, because they don’t have to replace that filter nearly as often.”

Water Pure Technologies and its dealer networks have sold to California fire jumper brigades, who parachute into forest fires and need drinking water onsite. They use mobile, hand-operated systems, which are also parachuted into the area. Water Pure Technologies dealers have also sold the Mobile Water ResQ U.V. units under a private label to the military, first responders, and disaster crisis groups. And the Department of Homeland Security has also purchased close to 90 units through their dealer network so far, Smokoff says.

“We’re trying to keep most of it American-made,” he says, noting that, although some parts had to be sourced elsewhere, “70 percent of our raw materials in our products are U.S.-made”—including the NASA-funded NanoCeram filter.

“This was the best one that I found that removes viruses and has a high flow rate,” Smokoff says. “These filters enable us to design and build systems that are able to really make a difference for whole communities.” ❖

A firefighter battles a fire in northern California. Water Pure Technologies and its dealer networks have sold mobile, hand-operated water filter systems to California fire jumper brigades, who parachute into forest fires and need drinking water onsite.

Miniaturized Vacuum Pumps Play Big Roles on Mars and Earth

NASA Technology

As its name implies, the Curiosity rover lowered into Gale Crater on Mars by sky crane in August 2012 has a lot of questions to answer. The most pressing, though, is whether the Red Planet has or ever had the necessary conditions to harbor life. One of the most important instruments the car-sized rover is using to investigate Mars' surface is called Sample Analysis at Mars (SAM). SAM includes a mass spectrometer that studies ionized samples of gas and rock by measuring the mass of the ionized molecules to determine their compositions and microstructures.

Like any instrument that is to be blasted out of Earth's gravitational field, SAM and its various components needed to be small and tough.

That includes vacuum pumps, which are used in mass spectrometers to decrease the air pressure inside the instruments to allow molecules from a sample to be ionized and manipulated for analysis. "To achieve the required sensitivity, mass spectrometers need to reach an internal pressure 10 orders of magnitude lower than the 760 torr atmospheric pressure on Earth," explains Bob Kline-Schoder, president of Hanover, New Hampshire-based Creare Inc. The pressure created by vacuum pumps inside a spectrometer is "not as low as it is in space, but it's pretty darn close."

The vacuum pump needed to be small, but that alone wasn't enough. Rodger Farley, a senior aerospace engineer at Goddard Space Flight Center, which led the development of SAM, says the pump had to be lightweight and very efficient. Additionally, it had to be able to withstand the heat sterilization required by planetary protection directives: exposure to 239 °F for up to 60 hours.

"No existing pump in the world could meet these excruciating requirements, which is why it had to be specifically developed for Mars missions under the NASA-contract environment," says Farley.

Technology Transfer

To help industry understand what NASA needed, the Jet Propulsion Laboratory (JPL) hosted a series of workshops in the late 1990s, says Patricia Beauchamp, who led the Centers for In Situ Exploration and Sample Return at the time and is now chief technologist in the Engineering and Science Directorate at JPL. The workshops brought together NASA engineers and industry representatives, and "Creare was one of the few that stepped up to the plate to

The vacuum pump Creare developed for NASA's Curiosity rover was based on a device about the size of a soda can, which the company was able to miniaturize to the size of a C battery (inset). Creare is now working on a similar vacuum pump for the ExoMars planetary rover (right), a joint mission between the European Space Agency and the Russian space agency Roscosmos scheduled to launch in 2018.

Image courtesy of the European Space Agency.

> “No existing pump in the world could meet [NASA’s] excruciating requirements . . . it had to be specifically developed for Mars missions under the NASA-contract environment.”
>
> — Rodger Farley, Goddard Space Flight Center

do the miniaturization required” for mass spectrometers in space, she says. “We tried to spread the market out, hoping that there would be more companies involved, because it was critical.”

She credits the company with having the foresight to work with NASA, through a series of Small Business Innovation Research (SBIR) contracts, to create the pumps.

Management of the vacuum pump development was shared between JPL and Goddard, where preliminary work was beginning on tools that would eventually be part of SAM. A Phase III SBIR contract was also later awarded to Creare for work on the Mars Organic Molecule Analyzer Mass Spectrometer (MOMA-MS), which will be flown on the ExoMars planetary rover, a joint mission between the European Space Agency and the Russian space agency Roscosmos scheduled to launch in 2018.

“Originally, Creare was developing a miniaturized version which was about half the size of the SAM pumps, but the development schedule did not conform to the MOMA schedule,” says Farley. “Still, this miniaturized turbo-molecular vacuum pump did eventually meet a test lifetime milestone of 1,000 hours. It is the smallest pump of its kind in the world.”

Creare’s work in this area of technology “makes for a nice success story,” says Dean Wiberg, manager of the Commercial Technology Partnerships Office for JPL at the California Institute of Technology. “At this point in time, with that genesis of the early SBIR work, they are making a commercial product that satisfies a real niche requirement in the market.”

Instruments used to assess chemical dangers following industrial accidents or terrorist attacks are currently too cumbersome to take into the field. Creare’s vacuum pumps could help mass spectrometers achieve the kind of reduction in size that would make them practical for use in the wake of a disaster, as well as in inspections and security screenings.

Benefits

Beauchamp notes that when NASA offered the workshops, only a few companies attended. “No one else bit at the time. There were people who were interested, but they didn’t do anything to develop a pump system, probably because at that time there were few commercial applications demanding similar technology.”

That’s changing, slowly, and Creare’s pump, now commercially available, has a bright future ahead.

“Mass spectrometers are useful for doing things here on Earth,” Kline-Schoder says. “If there’s a chemical weapons attack or toxic industrial chemicals are spilled, it would be a good thing to have an idea of what the danger is. Today, all of the instruments that do that kind of thing are really big and not portable.”

Creare is continuing to make improvements on its existing miniaturized vacuum pumps, he notes. “Over the years we’ve built one that’s about the size of a soda can, and now we’ve built this one for NASA that’s half the size, more like a C-cell battery.”

Having a miniaturized vacuum pump can help drive the development of smaller mass spectrometers, and Creare has been working with several companies to meet that demand.

“The vision of the future is you get rid of the instrument that looks like two microwave ovens sitting on top of each other at the airport screen line, and you have a shoebox-sized device that every single TSA agent is carrying with them, which they can use to sniff out possible explosives,” he says. “That would give them a little more flexibility. They can walk to the gate when you’re lined up and sniff your bag there, almost like bringing a dog wherever they are.”

The mining industry might also benefit from these miniaturized tools, using mass spectrometers to determine the contents of subterranean soil and oil deposits.

“There is a significant potential terrestrial market for miniature turbopumps with growth in compact and portable mass spectrometers,” says William Brinckerhoff, an assistant chief in the Planetary Environments Laboratory at Goddard. “Defense, healthcare, environmental, and industrial applications each have requirements for the type of mass spectrometer that this pump would enable. Some of the recent work making the pumps tolerant to vibration and shock could parlay into remote, autonomous, or field environments on Earth.”

On Mars, meanwhile, Creare’s pump has allowed Curiosity to find key ingredients for life such as sulfur, nitrogen, hydrogen, oxygen, phosphorus, and carbon, along with clay minerals that suggest a past aqueous environment—one that probably even included drinkable water.❖

Consumer Goods

You might be surprised by the number of space technologies in your home and among the products you use every day. This year's *Spinoff* shows how NASA technology can be found in your cell phone camera, golf clubs, ski goggles, and bottle of wine. Spinoffs are also improving large-scale 3D printers, enabling rechargeable hearing aid batteries, and strengthening sporting goods with nanomaterials.

CMOS Sensors Enable Phone Cameras, HD Video

NASA Technology

"People told me, 'You're an idiot to work on this,'" Eric Fossum recalls of his early experiments with what was at the time an alternate form of digital image sensor at NASA's Jet Propulsion Laboratory (JPL).

His invention of the complementary metal oxide semiconductor (CMOS) image sensor would go on to become the Space Agency's single most ubiquitous spinoff technology, dominating the digital imaging industries and enabling cell phone cameras, high-definition video, and social media as we know it.

Imaging devices based on metal oxide semiconductor devices had been attempted since the 1960s, but no one had ever succeeded in making the technology marketable. The little signal amplifiers had long been used in computer circuitry, but imagers using CMOS as sensors suffered from signal noise, among other problems.

Instead, a different imaging technology, using sensors based on the charge coupled device (CCD), allowed high-quality digital photography to come of age by the late 1980s. These image sensors comprise an array of photodetecting pixels that collect charges when exposed to light and transfer those charges, pixel to pixel, to the corner of the array, where they are amplified and measured.

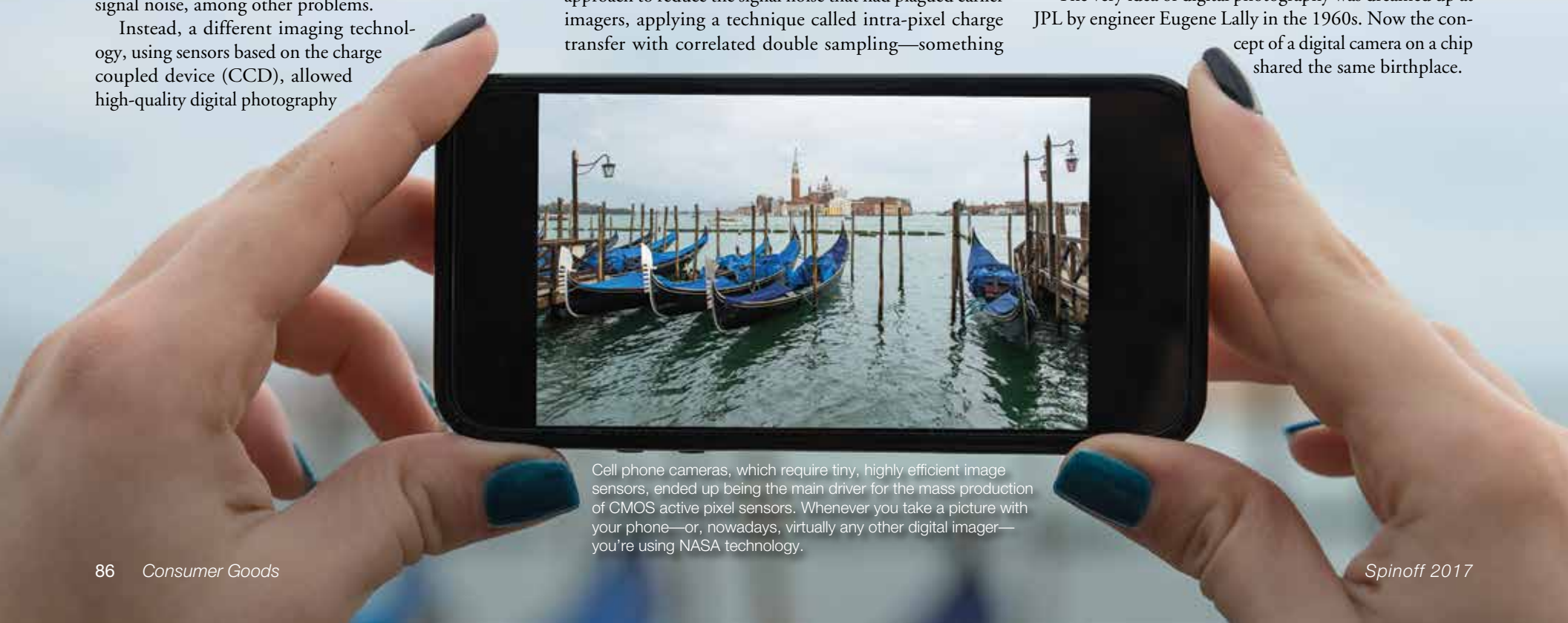
While CCD sensors are capable of producing scientific-grade images, though, they require a lot of power and extremely high charge-transfer efficiency. These difficulties are compounded when the number of pixels is increased for higher resolution or when video frame rates are sped up.

Fossum was an expert in CCD technology—it was why JPL hired him in 1990—but he believed he could make digital images with smaller and lighter machinery using CMOS technology to create what he called active pixel sensors (APS) (*Spinoff* 1999, 2002, 2010).

CMOS technology in general had improved since earlier attempts at using it for image-sensing, and Fossum hit on an approach to reduce the signal noise that had plagued earlier imagers, applying a technique called intra-pixel charge transfer with correlated double sampling—something already used in CCDs. Using this technique, he measured a pixel's voltage both before and after an exposure. "It's like when you go to the deli counter, and they weigh the container, then weigh it again with the food," he explains. The sampling corrected for the slight thermal charges and transistor fluctuations that are latent in photodetector readout, and it resulted in a clearer image.

Because CMOS pixels are signal amplifiers themselves, they can each read out their own signals, rather than transferring all the charges to a single amplifier. This lowered voltage requirements and eliminated charge transfer-efficiency issues. And it had the added benefit of allowing almost all the other camera electronics to be integrated onto the computer chip with the pixel array using conventional CMOS production processes, a development that would make CMOS-APS imagers more compact, reliable, and inexpensive.

The very idea of digital photography was dreamed up at JPL by engineer Eugene Lally in the 1960s. Now the concept of a digital camera on a chip shared the same birthplace.



Cell phone cameras, which require tiny, highly efficient image sensors, ended up being the main driver for the mass production of CMOS active pixel sensors. Whenever you take a picture with your phone—or, nowadays, virtually any other digital imager—you're using NASA technology.

> “Cell phones became the ‘killer application.’ Battery life and camera size are very important on a cell phone.”
>
> — Eric Fossum, inventor

Technology Transfer

By 1993 Fossum and his team knew they were onto something that could be huge for NASA missions and consumer electronics alike, but as they took their findings on the road, giving talks and publishing papers, they met with resistance from the digital imaging industry and even colleagues at JPL. Fossum attributes this skepticism both to earlier failures in CMOS imaging and to people’s instinct to protect their own livelihoods.

“Even a lot of my friends were negative,” he says. “The technology was basically trying to eat their lunch.”

Despite early doubts about CMOS’s potential, several companies signed Technology Cooperation Agreements with JPL and partnered with Fossum and his colleagues to develop the technology.

In 1995, Fossum became the first JPL scientist to license his own invention from the California Institute of Technology (Caltech), which manages the lab, as he, his then-wife and JPL colleague Sabrina Kemeny, and two other JPL coworkers founded a company, Photobit, to develop custom sensors. Caltech’s Technology Transfer Office was created that year, and the office granted Photobit an exclusive license.

“It was sort of the breakthrough spinoff that showed we could do tech transfer out of JPL, too, not just Caltech,” says Fred Farina, the university’s chief innovation and corporate partnerships officer. “So it was the pioneer, in terms of spinoffs out of JPL.”

The following year, Fossum left JPL to become the company’s full-time technological lead. In addition to designing custom sensors, Photobit licensed technology to companies like Kodak and Intel, although most of those early licenses didn’t lead to product lines. By 1997, however, CMOS was being taken seriously, and several companies invested in Photobit, including Schick Technologies, which also obtained—and still holds—an exclusive license for CMOS for dental imaging (see page 34).

The action camera company GoPro takes maximum advantage of the small size and high efficiency of CMOS digital image sensors, using the technology to build tiny, high-definition video cameras that users can affix to themselves, selfie sticks, or surfboards to capture their adventures in high fidelity.

That same year, Sandor Barna, now vice president of core technologies at GoPro, finished his graduate degree and took a job as an engineer at Photobit.

"It was a great example of a truly disruptive technology," he says, noting that CMOS did not yet perform as well as CCD imagers, but the potential to improve was clear. In addition, it promised to be easier to use with far lower power and could be more cheaply manufactured, he says.

While Photobit held an exclusive license to the technology developed at JPL and filed more than 100 of its own patents, company leadership was concerned that defending its intellectual property would prove difficult as several electronics giants began developing their own CMOS imagers.

Anticipating heavy competition, in 2001 the founders sold Photobit to Micron Technology, which could bring more resources and manufacturing capability to bear. By then, the company—and subsidiary Photobit Technology Corporation, created to handle custom-design contracts—had built a healthy business for itself, and CMOS's takeover of the imaging industry had begun.

Benefits

Before Photobit was sold, its sensors had made their way into webcams made by Logitech and Intel, as well as ingestible "pill cameras" that are still offered by Given Imaging as a noninvasive endoscopy technique. "I feel very good about that one," Fossum says of the so-called PillCam. "It's still used. It's become a huge industry."

Digital single-lens reflex cameras, better known as DSLRs, were also early adopters of CMOS technology, which allowed bursts of rapid shots at high resolution.

But by far the widest use of the small, low-power cameras enabled by CMOS technology has been in cell phones. "Cell phones became the 'killer application,'" Fossum says. "Battery life and camera size are very important on a cell phone."

As that industry drove Micron and others to turn out more and more CMOS imagers every year, resulting improvements to the technology and its manufacture drove costs down and quality up until CCD-based devices couldn't compete, even where size and power weren't priorities.

Now, outside of a few niche markets, virtually all digital still and video cameras use Fossum's invention.

When Photobit was sold, the original

"It was a great example of a truly disruptive technology."

— Sandor Barna, GoPro

GoPro cameras, which leverage the small size and high efficiency of NASA-invented CMOS active pixel sensors, were originally conceived as surfboard-mounted video cameras, an application that remains popular today.

Image courtesy of Kat Patterson

patents returned to Caltech, which still holds the intellectual property rights that haven't yet expired, and the world's top image sensor suppliers, such as Sony and Samsung, license the technology. Meanwhile, Micron spun off its image-sensing business into a company called Aptina, which ON Semiconductor purchased in 2014 for about $400 million.

Fossum says he was pleased that CMOS allowed the United States to recapture a portion of the imaging market, however briefly, before much of it was lost again to Japan, South Korea, and China. "Micron, GoPro, Omnivision, and a host of others generated tens of thousands—if not hundreds of thousands—of jobs in the United States because of this technology," he says.

GoPro remains headquartered in San Mateo, California, and employs most of its 1,500 or so workers—now including Barna—in the United States.

Barna says the video industry switched to CMOS cameras with the advent of high-definition video. To shoot video with so many pixels on a CCD-based camera would require dramatically more power, draining batteries and quickly overheating the machine, he says. "You would only be able to take very short bursts, and it wouldn't be the same experience at all."

CMOS sensors also allow both the device and the battery to be smaller, and small size is one of GoPro cameras' strongest selling points. The company's devices are designed to be mounted, usually on the body, to capture action sequences in video or still images, some at up to 240 frames per second.

"It would be very unpleasant to put a two-pound or four-pound camera on your head," Barna points out.

By 2013, more than a billion CMOS image sensors were manufactured every year, and by 2015, the technology's market, which also includes applications in the automotive, surveillance, and medical industries, reached nearly $10 billion.

For Caltech, the financial returns from the licensing, which fund research and education, are only part of the benefit of the CMOS success story, Farina says. "This helps motivate other researchers at Caltech and JPL, and for the whole culture of entrepreneurship it's really powerful to have good stories."

CMOS-enabled cell phone cameras gave rise to the "selfie" phenomenon, as well as a broader culture of online photo and video sharing. Here, President Barack Obama poses for a selfie with science popularizers Bill Nye, left, and Neil deGrasse Tyson, right.

He notes that cell phone cameras, which would likely not be possible without CMOS imaging, have also had an enormous cultural impact, bolstering the rise of social media, raising questions about police conduct, and bringing awareness to uprisings and crises around the world. "These things can be documented because people are all carrying around cameras," he says. "The impact went well beyond expectations."

"It's kind of amazing to me how much of a life of its own it's taken on," Fossum agrees.

Fossum, who was inducted into the National Inventors Hall of Fame in 2011, now teaches engineering and entrepreneurship at Dartmouth College's Thayer School of Engineering, where he is working on what he believes will be the next revolution in digital imaging. His Quanta Image Sensor would cram a billion pixels, each designed to sense a single photon, into an array no larger than those in current CMOS imagers, significantly enhancing low-light sensitivity.

Just as his first image sensor could be built using manufacturing processes that were well-established more than 20 years ago, Fossum is designing this next-generation imaging chip to be compatible with the enormous existing CMOS camera industry. "For factories building CMOS sensors, I think it will be pretty easy for them to switch to the Quanta Image Sensor if they want to do that," he says.

He's designing the sensor with the assistance of one of his PhD candidates, an experience that in some ways mirrors his early days at NASA. "I had some great organizational mentors at JPL," Fossum says. "Personally, I loved working for JPL—best job ever." ❖

Novel Threading Enables New Approach to Golf Clubs

NASA Technology

NASA scientists routinely pioneer advances in cutting-edge fields like lasers and computer chips, but sometimes it's the innovations they make in simple technologies that help optimize the machines of tomorrow.

More than 30 years after a researcher at NASA's Goddard Space Flight Center tested and demonstrated the significantly improved fastening ability of an altered screw-threading, the design continues to catch many engineers by surprise. Discovering the technology, says Cobra Puma Golf, has helped the company achieve the lowest-ever center of gravity in a golf club.

Screw threading dates back to antiquity, when grape and olive presses used an inclined plane wrapped around a shaft to convert minimal human effort into tremendous crushing force. Advances to this simple concept have been few and far between, with the screw finally beginning to be used as a fastener around 500 years ago.

An enduring problem, however, is that vibration can eventually jar screws and bolts loose. And few fasteners experience more intense vibration than those in a rocket engine. In the early days of the Space Shuttle Program, which used the first reusable rocket engines, NASA took an especially keen interest in fasteners that could endure the vibrations of repeated liftoffs, as well as extreme temperature variations that cause metals to expand and contract.

That was when the Agency came across an invention by Horace Holmes of Holmes Tool Company known as Spiralock threading, a slight alteration to traditional threading that promised considerably stronger joints.

Threading in female nuts and bolt holes had always precisely mirrored that of the male bolts that screwed into them, allowing them to perfectly follow each other's contours. The result, however, was that there was little if any pressure for most of the length of the connection, with about 80 percent of the clamp load being carried by the first two threads. Holmes' idea was to blunt the trough of the female thread with a 30-degree wedge ramp. The result was that most of the length of a bolt's threading ridge would be forced against the wedge in the nut, causing a more even distribution of the load along the length of the connection, with the first two threads now carrying just 25 percent of the load.

Holmes' creation was patented in 1979, but while the design came to be used in a handful of car engines in the early 1980s, it wasn't until the 1984 publication of a lengthy study by Goddard researcher James Kerley that Spiralock began to be used more widely. Kerley found that Spiralock nuts could withstand double the vibrations that would loosen a standard nut, and for 10 times as long. They didn't lose clamping power after a bolt and nut combination was torqued on and off 50 times, far exceeding NASA's demand for a fastener that could be reused at least 15 times.

Shortly after Kerley's study was published, Spiralock was applied to more than 750 tube clamps, joints, and brackets in a set of Space Shuttle main engines, where it easily withstood further testing (*Spinoff* 1987, 1995).

In the early days of the Space Shuttle Program, which employed reusable rocket engines, NASA looked for fasteners that could endure repeated, intense vibrations without jarring loose. A researcher at Goddard Space Flight Center came across Holmes Tool Company's patented Spiralock threading. He tested the invention meticulously and found it exceeded the Agency's demand. Spiralock came to be used on more than 750 tube clamps, joints, and brackets in Space Shuttle main engines and, after the test results were published in 1984, a wide array of industry applications, from diesel engines to pacemakers.

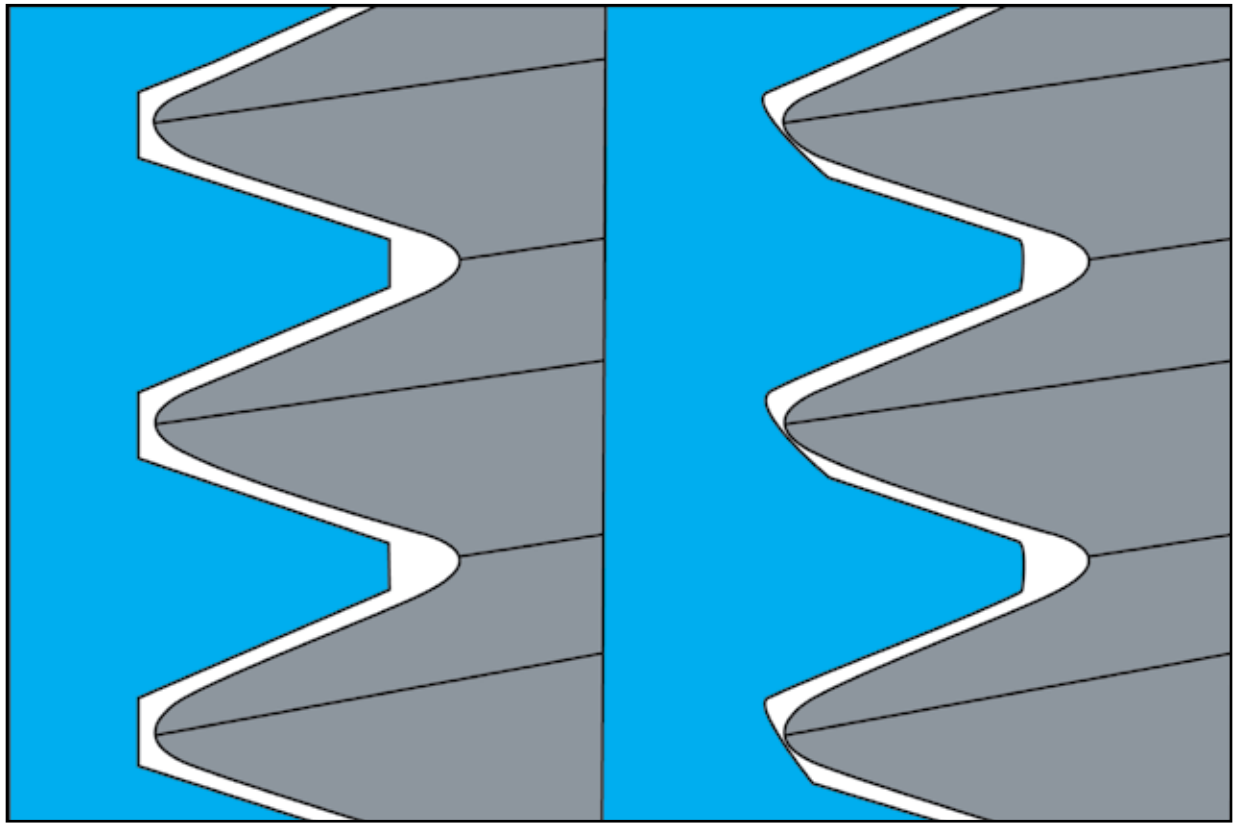
The design soon came to be incorporated into missiles, diesel engines, oil wells, seismic vibrators, broadband fiber-optic networks, human joint implants, pacemakers, and many other systems. Reflecting the industry's indebtedness to NASA's work validating the technology, in 1985 a prominent member of the American Society of Mechanical Engineers wrote a letter congratulating Goddard's director for "having such a meticulous experimentalist and practical dynamicist as Mr. Kerley on its staff" and for funding "basic technical work of such broad interest to the Government and industry technical community."

Technology Transfer

The similarities between spacecraft design and golf club engineering may not be obvious, but they're there, insists Mike Yagley, director of innovation, research, and testing at Cobra Puma Golf, based in Carlsbad, California. Engineers in both fields have to consider various alloys, worry about weight, strength, and durability, and otherwise bring together a wide variety of factors to create one optimized design, he says.

In early 2013, a few employees of the Center for the Advancement of Science in Space (CASIS), which manages the International Space Station's (ISS) U.S. National Laboratory, stopped by Cobra Golf's booth at the PGA Merchandise Show in Orlando, an encounter that led to an ongoing partnership. "They were taken aback by how much technology goes into designing a golf club and getting it to perform," he says. "There are an awful lot of things we're doing that are similar to what you're doing in aerospace applications, where you've got to make something lightweight and strong."

Before long, the company was consulting with employees of various NASA field centers, and by September 2014 CASIS had secured Cobra Puma Golf a slot as a customer for a research payload to the ISS. The company sent up 20 tiny "spaceport doors," modeled after the ISS cupola, for a one-month experiment testing the hypothesis that silver would deposit more uniformly and with larger crystalline growth in zero gravity, resulting in higher durability.



The innovation behind Spiralock threading, on the right, is a 30-degree wedge ramp in the trough of the female thread. This forces the thread on the bolt against the ramp in the nut, distributing pressure along the length of the thread, whereas standard threading, shown on the left, puts about 80 percent of the clamp load on the first two threads, with most of the threading making little contact.

The door was to be a unique feature of Cobra Puma Golf's KING LTD Driver, but an unforeseen problem had arisen. "The spaceport door turned out to be in an extremely high-vibration, high-load environment," Yagley says. After hitting golf balls over and over, the portal, which screws into the bottom of the club's head, began to come unscrewed, much like a bolt in a rocket engine after repeated use.

Having come to respect NASA's problem-solving approach, Yagley researched the Agency's use of fasteners in high-vibration environments and came upon Spiralock threading. "We incorporated that thread around our spaceport door to help alleviate the effects of vibration occurring during impact," he says.

To cut the thread into the clubs, the company acquired a licensed cutter and gauge from Spiralock, now part of Stanley Engineered Fastening. Yagley says the spaceports now hold fast, and the company started selling the drivers in November 2015.

Benefits

"The door gives access to the inside of the golf club, which no one has had or seen before," Yagley says.

Normally a finished driver head is just under its target weight—typically around 200 grams—because it's easier to add weight than to subtract it, he explains. Then, just enough hot melt—a sticky substance which doubles as weighting material and debris catcher—is injected through a small hole in the sole of the club.

However, "we would prefer not to have to put the hot melt in," says Yagley, noting that it's hard to control where the mass goes inside the club, and it can also affect acoustic properties. Instead, with the spaceport door in the KING LTD Driver, a tungsten weight can be inserted. The metal can be filed to the precise weight necessary for each club before it's locked in place. The aluminum door itself, which features a polycarbonate window into the club's interior, also serves as a 16-gram weight.

All this has helped Cobra Golf make what it believes is the first zero-center-of-gravity golf club, meaning the center of gravity for the entire club is on the neutral axis, an imaginary line extending back from the center of the club's face, maximizing the transfer of energy from club to ball. "For 500 years, centers of gravity have been above that line," Yagley says. "Everybody's been trying to get the center of gravity lower, and we believe we're the first to place it on the neutral axis."

He adds that the door to the club's interior also allows the company to make custom clubs, adjusting the size and position of the tungsten weight to suit individual golfers' styles. "This is the best golf club we've ever made, and we think it's just the beginning," he says.

As for the ISS experiment, Yagley says the results are part of ongoing research that should pay off in the future, especially as the company continues to partner with NASA, sharing knowledge about construction materials, processing, and testing.

"As we all march down this path together, I'm very confident that not just our industry but all industries are going to benefit from the research being done on and for space applications." ❖

Cobra Puma Golf wanted a "spaceport door" to screw into the bottom of its KING LTD Driver in celebration of the testing the company was doing on the ISS. The vibration of repeated drives, however, would cause the little portal to come unscrewed. The company researched NASA's techniques for dealing with intense, repeated vibration and came upon Spiralock threading, which now holds the doors firmly in place. The access to the inside of the club head also allows the clubs to be more precisely weighted, with a lower center of gravity.

The "spaceport door" enabled by Spiralock threading in Cobra Puma Golf's KING LTD Driver allows it to be what the company believes is the first club with a zero center of gravity, meaning the center of gravity for the whole club runs through the center of the driver's face. It's a feat golf club makers have been attempting for centuries.

Blue-Light-Cancelling Lens Gives Skiers a Clearer View

NASA Technology

Of all the colors the human eye is capable of seeing, it is particularly sensitive to blues and greens, which comprise the middle wavelengths of the visible electromagnetic spectrum. But our sensitivity to these colors comes at the expense of peripheral hues, like red, when the two colors are seen simultaneously. The phenomenon, called center-loading sensitivity, can interfere with visibility in certain situations like spotting targets or judging distances.

In the early 1990s, Ames Research Center senior scientist Len Haslim investigated technology that would allow these peripheral hues to stand out for detecting camouflaged objects in forests and jungle environments. High-cost electronics and photographic technology had been used for the purpose, but Haslim went on to develop a simpler, cost-efficient method that uses an optical filter to cancel the green light reflected off of the flora and augment the non-green colors of the camouflaged objects. Seen through the lens, the plant's green colors appear black or gray while the other colors, now amplified, would "pop," or stand out.

But Haslim also noticed that the optical filter didn't just make it easier to pick out camouflaged objects—it also enabled him to detect plant distress. Dying plants' chlorophyll content changes, and these changes are reflected first in the red and infrared portions of the spectrum. In addition, distress causes a collapse in the part of a plant's leaf called the mesophyll, which also reveals itself through red and infrared reflectance. These early warning signs are undetectable by the human eye, and by the time a plant shows a noticeable decline, it may already be too late. But with Haslim's optical lens, a plant's distress stood out in red, pink, and coral hues, and in enough time to possibly save it from dying.

Technology Transfer

As an optical scientist and the owner of an aerial photography business, Robert Brock recognized the value of having a cost-efficient optical filter for a number of applications. "To be able to cancel light frequencies and amplify others without having to buy electronic equipment created a huge potential in the market for these lenses," he says.

In 1994, his company, Portland-based Optical Sales Corporation (now NASTEK), entered into a Space Act Agreement with Ames to commercialize the technology Haslim had developed. With additional funding from the U.S. Department of Agriculture, the firm performed the additional research and development needed to come out with its Plant Stress Detection glasses for assessing plant health (*Spinoff* 1996), as well as a similarly functioning filter for use in digital, film, and video cameras for large-scale remote sensing activities. Golf course superintendents, crop managers, and foresters use the lens for early disease detection and trouble-shooting watering problems, among other issues, saving them money and resources.

Now the company is using the same foundational technology derived from NASA research to help skiers see terrain more clearly. For them, it's not the color green but rather blue that can be a hindrance. Blue light comprises wavelengths of the visible spectrum that are easily scattered by air molecules, which is the reason the sky appears

The blue light scattered by air molecules creates a particular haze around mountainsides that interferes with human vision. NASA optical filtering technology is now used in ski goggles that can increase visual acuity and depth perception in these conditions by an average of 12–15 percent.

Following research and development that began in a partnership with NASA, NASTEK now manufactures ski-goggle lenses that use NASA technology to optimize visibility on the slopes. In 2015, the company worked with Optic Nerve to create a line of ski goggles that are used by professional and amateur skiers and snowboarders, as well as ski patrollers.

that color. But this scattering also causes blue light waves to bleed into mountainsides and other land features, creating a haze that can be troublesome for skiers visually, especially on overcast days. To remedy that, NASTEK develops ski goggles that cancel out a significant amount of blue light. Among other commercial partners, the company has teamed up with Wheatridge, Colorado-based Optic Nerve.

Benefits

Optic Nerve's rose-tinted spherical NASTEK lens ski goggles, which arrived on the market in fall of 2015, are a cut above the rest in filtering blue light, says vice president Tom Fox. "The industry standard lies at around 79-80 percent filtration," he notes. "Our lens is up there around 95 percent, which results in an incredible definition of terrain in flat light as well as bright sun conditions." Brock adds that for people who aren't color blind, that means an average increase of 12-15 percent in visual acuity and depth perception.

The lens is also versatile. Some ski goggles are designed for low to variable light conditions but are not ideal for bright conditions, because they let in an intense amount of sunlight that can be uncomfortable on the eyes. For that reason many skiers switch lenses depending on the weather. But the NASTEK lens handles low and bright incoming light equally well.

"We have professional skiers and ski patrollers who wear them every single day telling us they never have to change the lens," adds Mae Harris, Optic Nerve's communications manager. "That's a pretty good sign of its dynamic range."

Besides the blue-light cancellation technology, Fox points out other features that make these ski goggles more than worth their price tag, which he says is more affordable than other leading brands. First, a careful design prevents air gaps, and therefore fog, from forming in the goggles. Second, the high-grade polycarbonate lens is impact-resistant and provides complete protection from ultraviolet A, B, and C radiation.

Also, in order to create a reflective surface, many lens makers apply a thin titanium coating to the outside of the lens, where it's easy to scratch. NASTEK applies the reflective coating to the inside of the lens instead. "The outside of our lens is pretty robust as far as durability is concerned because you don't have that thin layer taking the brunt of all the impacts and cleanings and handling," he says.

NASTEK manufactures lenses for some of the biggest eyewear companies on the planet, but Optic Nerve was the first North American company it teamed up with to incorporate the blue-light-cancelling technology. "They are very, very sharp," Brock says of Optic Nerve. "They really understand what their customers want and understand the importance of quality control. We're very proud that they want to be involved with our lenses." ❖

Rechargeable Hearing Aid Batteries Draw from NASA Research

NASA Technology

We often imagine that inventions are born whole: Thomas Edison creates the incandescent light bulb and lights up Christie Street in Menlo Park on New Year's Eve, stunning the world and single-handedly ending the tyranny of night.

This is rarely the reality, however. In this case, arc-lamp street lights already existed in 1879, as did incandescent lights, albeit impractical ones. Edison and his team just hit on the right filament: carbonized bamboo. The invention built on more than 50 years of experimentation by others.

Likewise, few modern technologies are the product of a longer, harder slog than the silver-zinc battery, which is finally making an early foray into the consumer market in the form of a line of rechargeable hearing aid batteries, more than two centuries after its first invention.

Considerable effort and resources have been dedicated to making a practical version of the silver-zinc battery, mainly because it can offer more energy per ounce than any other battery couple. Its development, however, has been marked by slow, incremental progress, dead ends, and the occasional breakthrough—a major one of which occurred at NASA's Glenn Research Center, then known as Lewis Research Center.

The main problem with the silver-zinc couple was that its electrodes—the cell's negative and positive electrical conductors—were soluble and deteriorated quickly, especially the negative zinc electrode. In the late 1920s, French Professor Henri André finally made the first practical silver-zinc battery by using a membrane to separate the two electrodes, preventing active materials from migrating between them and causing deterioration. It was a development that presaged the work that would take place at Lewis some 40 years later.

During World War II, the U.S. military, especially the Navy and Air Force, advanced effective silver-zinc primary—or non-rechargeable—batteries, which it still uses to power submarines, torpedoes, missile propulsion systems, and other devices.

Several early NASA spacecraft, including the Apollo command module, used silver-zinc batteries. The Agency worked hard to make such batteries rechargeable, with some major advances made at Glenn Research Center, then called Lewis Research Center. Rechargeable silver-zinc batteries didn't make it into space, but NASA's research and development served as a starting point for anyone trying to develop them.

In its early days, NASA also used such batteries, for example in launch systems. The Agency was especially interested in a rechargeable—or secondary—version for the long-term, lightweight power it could provide for space systems, but electrode deterioration remained a problem, significantly impeding performance after several deep discharge and recharge cycles. Zinc oxide released by the zinc electrode would dissolve, degrading the electrode, changing its shape, and reducing its surface area. It would also plate back onto the electrode and form structures that could pierce through the cell separator, ruining the battery.

The problem was compounded if the battery was heat-sterilized, a requirement for all Mars rovers to ensure they don't populate the Red Planet with Earth microbes.

During the 1960s, NASA carried out many experiments, primarily at the Jet Propulsion Laboratory, Goddard Space Flight Center, and Lewis, to resolve these challenges. Researchers tried other materials in the cell separator, additives to the electrodes and electrolyte, different cell geometries and methods of construction. These often led to minor improvements, but a comprehensive 1968 NASA report, "Batteries for Space Power Systems," noted the persistence of many of the same limitations.

The report did make mention, however, of an experimental cell using a novel, inorganic ceramic separator developed by the Astropower Laboratory of Douglas Aircraft Company, a frequent collaborator with Lewis on silver-zinc batteries, which showed promise but lacked sufficient data.

Astropower had been working to develop an inorganic ion exchange membrane for a fuel cell for Lewis, and researchers at the field center suggested that a similar separator might work in a rechargeable battery. In 1965 Astropower and Lewis began working on a separator that would begin to mitigate many of the challenges to rechargeable silver-zinc batteries.

By 1972 Lewis had tested and proven silver-zinc cells based on a specific inorganic separator and a specially prepared zinc electrode, which were able to function as a rechargeable battery after heat sterilization. The cells were still only reliable up to 400 to 500 shallow discharge cycles, as opposed to the 10,000-cycle life of the nickel-cadmium batteries commonly used in space applications of the time, but they could result in batteries one-third the size of nickel-cadmium units, a substantial saving in weight.

The cells also exhibited none of the zinc electrode shape-changing and degradation seen in typical silver-zinc batteries. A 1972 paper out of Lewis titled "A Versatile Silver Oxide-Zinc Battery for Synchronous Orbit and Planetary Missions" called this durability "striking" and "most unusual," considering that the electrode hadn't been treated to inhibit shape-change.

Astropower went on to create an even more effective inorganic-organic separator that further extended silver-zinc battery life and eliminated problems of low conductivity exhibited by other inorganic separators. Lewis started a separator development program in 1973, obtaining a license for Astropower's inorganic-organic separator and experimenting with it heavily to discover why it worked as well as it did. Finally armed with this understanding, the team went on to create three alternate recipes with superior performance, as well as a method for efficiently manufacturing such separators, all of which it announced in 1979.

Whereas Astropower's cells based on its inorganic-organic separators lasted about 150 cycles at 50 percent discharge, Lewis' survived more than 200. The Astropower separators were also brittle and difficult to work with, but Lewis managed to make its versions flexible, as well as more uniform, which produced a more uniform current density and likely was responsible for extending battery life. Based on the materials used and the manufacturing process the engineers came up with, their separators also only cost about 35 cents per square foot, compared to $1.25 for their Astropower predecessor.

Technology Transfer

Despite all of this research, NASA has not made heavy use of the secondary silver-zinc battery, likely because of remaining limitations to the number of times they can be recharged and major advances to nickel-cadmium batteries in the mid-1970s. Nickel-cadmium had already been the Agency's preferred choice for many applications. Lithium-ion batteries, which came along in the 1990s, now offer nearly as high an energy-to-mass ratio as silver-zinc cells, and they can be recharged many more times.

Meanwhile, the costs associated with silver electrodes, along with the relatively short cycle life, have largely kept the technology out of commercial markets—until recently.

Zinc Matrix Power, now known as ZPower, was founded in Camarillo, California, in 1996 for the purpose of commercializing the rechargeable silver-zinc battery. At the time, the technology could still only endure 10 to 30 deep discharge cycles before losing significant capability, so the company picked up where NASA and others had left off.

The results of most of the Agency's research and development was publicly available, and the company's engineers used them as part of their starting point. Ross Dueber, the company's president and CEO, also had personal knowledge of some of that work. Early in his Air Force career, he was assigned to the Battery Branch at Wright Aeronautical Laboratories, which frequently collaborated with NASA on rechargeable battery systems, including some based on silver-zinc technology.

"What we've done at ZPower is take that chemistry that NASA did a lot of development on, along with the military, and moved it into the commercial sector," Dueber says.

But it took another long struggle to get it there.

The company focused on improving all four active components of the battery—the two electrodes, the electrolyte, and the separator. In its final product, among other improvements, the company uses a proprietary coating on its silver electrode to improve conductivity, a paste material to reduce zinc ion diffusion from the zinc electrode, and a specialized electrolyte that extends the life of both electrodes. The engineers also patented designs for stacking the separators.

Another company's work on silver-zinc batteries under Small Business Innovation Research contracts with Glenn and NASA's Johnson Space Center in the early 2000s brought ZPower's attention to a third company, Advanced Membrane Systems, which had provided battery separators for testing. ZPower bought the patent and all rights to the technology.

> "It's an area that hasn't received a whole lot of attention over the years, but with a new focus on wearables, people are looking more and more at small, high-energy batteries."
>
> — Ross Dueber, ZPower

That's in addition to the 100 or so of its own patents the company has taken out over the years.

"There was a tremendous amount of development that went into it," Dueber says.

The batteries can now survive 500 to 1,000 discharge cycles without losing significant capacity.

After more than a decade of research and development, the company announced in 2007 that it would launch a line of laptop batteries the following year. However, Dueber says, the economic crash of 2008, coupled with a sharp rise in the price of silver, made affordability a serious obstacle. The company went back to the drawing board.

The smaller the battery, the less the price of silver is an issue, Dueber explains. So ZPower hit on another application: hearing aids. In late 2013—17 years after its founding—the company released its first major product line.

With a viable, truly rechargeable silver-zinc battery finally in hand, though, the company expects that hearing aids represent just one of a number of markets ripe for conquest.

Benefits

Traditional hearing aids run on disposable batteries, usually of the zinc-air variety. These have a high energy-to-mass ratio but can't be recharged. Rechargeable battery types such as nickel-metal hydride haven't been able to carry enough energy to last a full day in the small sizes required for hearing aids.

ZPower rechargeable silver-zinc hearing aid batteries fit into a specialized door that can be retrofitted onto most existing hearing aids. The door carries a charge from the charger to the battery, eliminating the chore of removing and inserting the batteries.

As a result, hearing aid users have to replace their batteries every week or so, causing a two-fold inconvenience: changing out the tiny batteries requires considerable dexterity and visual acuity, which can be an issue for the seniors who are their primary users, and the batteries die unpredictably, encouraging users to shut them off whenever possible and inevitably leaving them without hearing at inconvenient moments.

"Can you think of any other high-end electronic device where you've got to do that?" Dueber asks. "It's just unfathomable in this day and age."

There are also environmental implications to the disposable-battery model. Around 1.5 billion zinc-air hearing aid batteries end up in landfills every year, according to the company.

Lithium-ion batteries are the only ones that compete with the silver-zinc couple in terms of high energy storage. These, however, are prone to a phenomenon known as thermal runaway, which, in rare but disastrous cases, causes them to combust. "You want to make sure what's in your ear is not going to catch fire or explode," Dueber points out. This is not a possibility with silver-zinc batteries, which use a water-based chemistry.

Lithium-ion batteries also require more packaging and other components that take up a larger percentage of their space the smaller they get, so it's a less efficient technology for tiny batteries.

To address the difficulty of removing and inserting the batteries, ZPower batteries recharge inside the hearing aid. They fit into a specialized door that can replace the battery door on most existing hearing aids, and the door carries the charge from the charger to the battery. "Now you just take the hearing aids out and put them in the charger," Dueber says, adding that the battery can reach full charge overnight.

A charge lasts from one to two days, and the company recommends replacing the batteries once a year. At $25 to $30 for each battery, that's a considerable savings compared to what a year's worth of disposable batteries would cost.

ZPower also developed a recycling process for its batteries, each of which is 95 percent recyclable metal. Users trade in the batteries at their audiologist's office, and the company collects them and sends them to a refiner for recycling. "Because of the fact that we use a precious metal, it's really cost-effective for us to bring it back and recycle it," Dueber says.

The company launched its product line through the Beltone network of hearing aid providers and plans to expand beyond. It's also in talks with a couple of manufacturers interested in building the batteries into their hearing aids, and Dueber is working toward a contract with the Department of Veterans Affairs, which processes 8,000 to 10,000 orders per week for hearing aid batteries at its logistics center. "The benefit we would deliver to the program is, all of that goes away," he says.

The rechargeable battery system won a 2016 Consumer Electronics Show Innovation Award and a 2016 Edison Award.

Manufacturing all of its products in Southern California, ZPower expanded from about 35 to 100 employees after its product launch. Now the Thomas Edison of rechargeable silver-zinc batteries, the company sees further expansion on the horizon.

"It's an area that hasn't received a whole lot of attention over the years, but with a new focus on wearables, people are looking more and more at small, high-energy batteries," he says. For example, the company is working with a sunglasses manufacturer on a pair of non-losable sunglasses. A cell phone app would locate a beacon in the glasses powered by a ZPower battery.

"We really view this as an enabler for new product designs going forward," he says. "Hearing aids are just our first market of many."❖

Disposable hearing aid batteries die unpredictably, which tends to encourage users to turn them off at times to conserve power and inevitably leaves them without hearing at inconvenient times. On a full charge, the rechargeable silver-zinc batteries that ZPower built off of previous research and development by NASA and the military reliably last all day and then some.

Large-Scale 3D Printer Brings Manufacturing to the Masses

NASA Technology

When the nearest Home Depot is out of reach and Amazon.com doesn't deliver, finding spare parts or a new tool can be a challenge. That can be true whether you're orbiting through space or in a shantytown in Kenya.

In recent years, with the spread and increased sophistication of 3D printers, NASA has been exploring a new solution: printing what it needs—so far at the International Space Station (ISS), but aiming one day to use the technology to help enable crewed missions into deep space.

The same idea appealed to a group of young innovators then working at Johnson Space Center, who hope to bring the technology to developing countries, where they believe it could alleviate some difficulties facing entrepreneurs and aid workers.

Most 3D printers extrude streams of heated plastic, metal, or other material to build objects, layer by layer. The printers follow designs created on a computer that can be shared electronically—helpful for space applications, where an engineer on Earth can create and test an object and then send the design file for printing in space.

A team including engineers from Marshall Space Flight Center and 3D printing company Made In Space built the first 3D printer ever shown to work in zero gravity. It was installed on the ISS in 2014 and successfully performed a course of 25 test prints, including a calibration coupon, a torque test, and a clip for the mini CubeSat satellites.

The most famous print in the series was the final one, a functional ratchet—the first item printed from a design sent from Earth instead of preloaded on the printer before it launched. The project, accomplished from design to successful space-print in one week, confirmed the broad potential for 3D printing for future space missions.

"If you can transmit a file to the station as quickly as you can send an email, it opens up endless possibilities for all the types of things that you can make, from CubeSat components to experiment hardware," Niki Werkheiser, the space station 3D printer program manager at Marshall, said in an article published by NASA soon after the ratchet printed. "We even may be able to make objects that previously couldn't even be launched to space."

Technology Transfer

Samantha Snabes and Matthew Fiedler met when they were working at Johnson in 2009, but they shared another interest. Both were interested in international development work and had volunteered with the Johnson Space Center Chapter of nonprofit Engineers Without Borders. The two, along with other friends at Johnson and in their volunteer community, began musing about the similar challenges faced by astronauts out of reach of a supply chain and communities in the developing world.

The team wanted to make it possible for groups in developing countries, whether aid agencies, small businesses, or schools, to buy and use large-scale 3D printers—the company calls the printers "human scale," alluding to the idea that they can print full-size, functional objects as opposed to miniaturized prototypes.

"The idea was to enable someone to own their own personal factory and ultimately control their supply chain so they could print solutions locally, which we thought

In 2014, astronauts printed a functional ratchet on the ISS from a design created on Earth and emailed into space. NASA is interested in developing 3D technology to help supply long-duration missions with items the crew didn't, or couldn't, bring with them.

would have been an asset for some of our peers when we volunteered at Engineers Without Borders," explains Snabes, who with Fiedler and four others founded re:3D Inc. in Houston to make the concept into a business.

But they couldn't find an affordable, industrial large-scale 3D printer to incorporate into their business model. Big printers came with big price tags, around $100,000, and they weren't built to be portable.

So Fiedler decided to build his own. The re:3D chief engineer, who traces his background to mechanical, industrial, biomedical, and biomechanical engineering, says he started building things as a kid and kept right on doing it. At NASA, he used and expanded those skills in the human research program at Johnson, in the neuroscience lab.

"We were primarily interested in mitigating the effects of microgravity for the astronaut crew," Fiedler says, and to that end, "we not only worked with a lot of software and hardware, but we created devices and machines that would test the astronauts.

"So I would work with programming machines that would simulate motion environments for the astronauts. It translates a lot from the hardware/software side, directly into creating a machine that moves like the 3D printer," he says.

All that experience, from his childhood tinkering days to the high-tech work he was doing at NASA, paid off. Fiedler went into his garage workshop with a blank piece of paper and some aluminum for the frame, and "from there I figured out how to put everything together to make it strong and simple, and simple to manufacture."

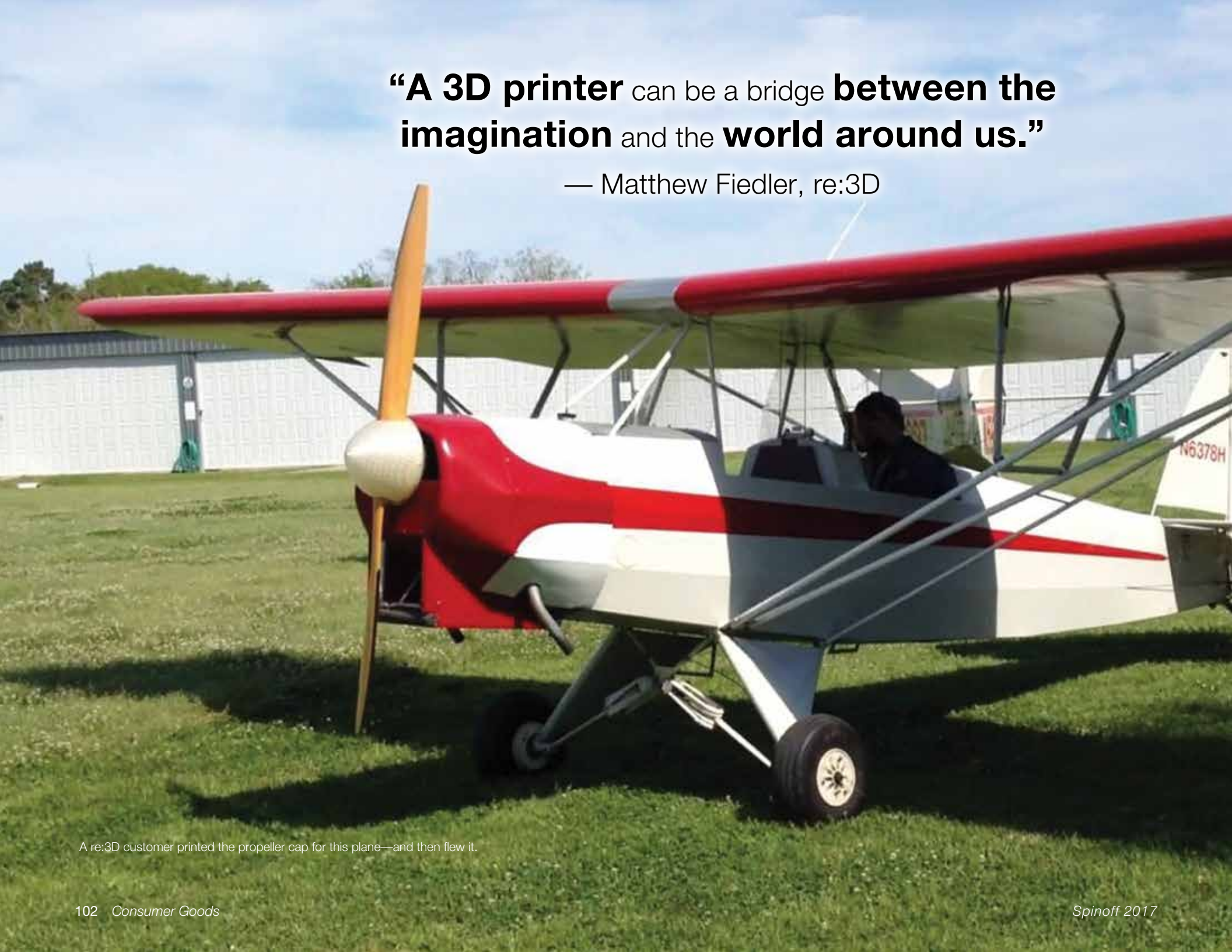
Benefits

re:3D branded its printer the Gigabot. In the standard configuration, it can print items up to eight cubic feet, or 30 times larger than competing desktop models, the

re:3D printed this surfboard in four pieces and brought it to Sligo, Ireland to surf it for an event called SurfSummit. The company says their goal is to democratize manufacturing, so as many people as possible, including in the developing world, can print their ideas in solid form.

“A 3D printer can be a bridge **between the imagination** and the **world around us.”**

— Matthew Fiedler, re:3D



A re:3D customer printed the propeller cap for this plane—and then flew it.

The founders of re:3D drew on experience at Johnson Space Center to design and sell a large-scale 3D printer at a low cost. The standard configuration prints items up to eight cubic feet, or 30 times larger than competing desktop models.

company says. An XL configuration can print even larger items, up to 10 cubic feet.

The Gigabot is not as sophisticated as some of the other large-scale printers available, but Fiedler estimates it delivers about 85 percent of the quality at just 10 percent of the price, with units starting at $8,550.

"The very expensive printers are expensive because that last little bit of quality is very difficult," he says. "We didn't try to give you that $100,000 machine, but we provide a tremendous capability that you've never had before for a much lower price point."

Gigabot is also sturdy, reliable, and easy to use—a plus when you're far away from a repair facility or can't afford for the machine to go down, whether that's in space or on Earth. "The best theory is to make things as simple as possible but no simpler. And that's not an easy thing to do. I took a lot of inspiration from growing up on a farm: you can't be breaking down on the field," Fiedler says.

Although the original goal was to bring the printers to the developing world—and the business early on got seed money from Start-Up Chile to launch in Latin America—the founders quickly realized there was a market for their affordable, large-scale printer in the United States and other developed countries as well.

Since its start in 2013, the company has sold more than 350 units around the world, including delivering units to both Johnson and Langley Research Center—a particularly sweet accomplishment for the former NASA employees. "We're very excited about giving them the capability as well," Fiedler says. "I think anyone would feel good about being able to close that circle."

But he says the bigger joy for the re:3D team is bringing manufacturing power to people and places that, unlike NASA, never could have afforded a human-scale 3D printer before. Helping push forward that objective, the company also donates a Gigabot printer to a recipient chosen through a contest for for every 100 printers sold. So far, one printer was sent to a Colombian man printing prototypes for myoelectrically controlled prosthetics, in particular arms and hands, and a second was sent to a community group in the Kibera slum in Kenya, where it is being used to teach students business skills and how to incorporate 3D printing into their projects. A third was donated to a group in Nigeria using Gigabot to promote reading in remote areas.

"The thing that I most enjoy is democratizing the capability to manufacture: offering the most capability possible for the lowest possible price. That way you can get it out to as many people as possible," says Fiedler.

"Everyone has good ideas, but maybe they didn't have the way to realize those ideas. Now a 3D printer can be a bridge between the imagination and the world around us, and they can use it to bring their ideas into the world." ❖

Professional Development Program Gets Bird's-Eye View of Wineries

NASA Technology

Virginia might not yet rival California when it comes to wine production, but a growing number of wineries and vintners are cropping up across the commonwealth. Hundreds of acres of grapes are planted annually, ranging from sweeter varieties to more traditional chardonnay and cabernet species, and wine growers use detailed maps to keep track of which grapes are growing best across their property.

Ask vintners how many acres they have, and they can give you a number off the top of their heads. But ask where the property lines are, or whether the fields cross into another county, and the answer is less clear. NASA's Langley Research Center found some researchers to help Virginia and its wine makers understand where grapes are being grown.

Langley houses the National Program Office for NASA's DEVELOP Program, in which up to 400 students and professionals from across the country annually get the opportunity to build their capacity to work in the science, technology, engineering, and math fields. Participants work on one or more of the approximately 80 environmental and public policy projects the program takes on each year using Earth observations collected from NASA tools.

In 2015, a handful of participants used data and images obtained by the NASA-built Landsat satellites to help identify the boundaries of vineyards across Virginia as a way to help the Virginia Wine Board, based in Richmond, Virginia, better understand where grapes are grown in the commonwealth.

Technology Transfer

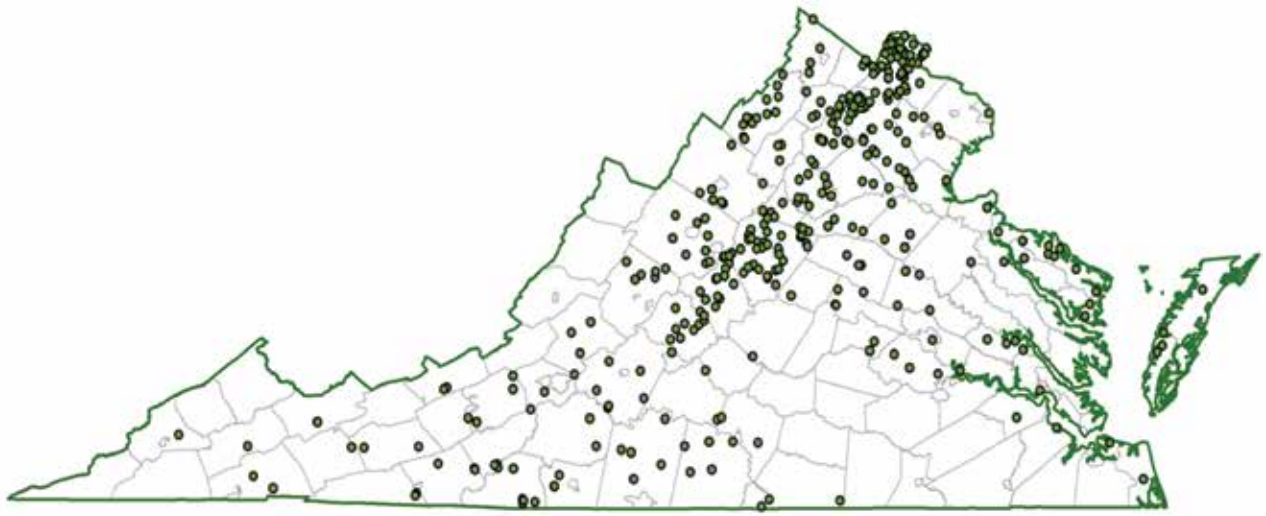
DEVELOP has nodes at 12 locations across the United States, including NASA field centers and cooperative locations. Participants are often working toward undergraduate or graduate degrees, or they may be in the work force looking to advance their career or make some sort of transition, says Kent Ross, Langley scientist, national science advisor for DEVELOP, and one of the group's advisors on this project. The program started in 1998 when student interns at Langley co-authored a research paper on remote sensing capabilities while, at the same time, the Digital Earth Initiative kicked off a project to increase public access to Federal Earth science information. Candidates compete to participate, with a selection rate of about 25 percent, Ross says, with some taking part in more than one research opportunity.

This was, in fact, DEVELOP's second project with Virginia wines. In an earlier effort, a team partnered with the Virginia Department of Agriculture to examine suitability for siting vineyards across the commonwealth according to current and forecasted temperatures.

The program hit on this next project because the self-reported responses to an annual member survey weren't providing the Virginia Wine Board with total vineyard acreage at the same level of confidence as previous surveys from the U.S. Department of Agriculture (USDA). The USDA had stopped providing that kind of data several years prior. "The Wine Board felt the survey they did was pretty successful, but they didn't have a way to validate the information in a secondary way," Ross says. "That's what they were looking to us for."

The Wine Board provided the results of the survey and vineyard addresses, which the DEVELOP team used as a starting point for investigation.

The researchers "carefully and laboriously scanned aerial photos of many square miles of Virginia in the areas where wine production is intense," Ross says, and they were able to identify field boundaries. "The patterns you can see in the vineyards, especially because of the trellising that's done for the vines, make them distinctive and allow those fields to stand out from other orchards or crops." The team was able to verify about 80 percent of the acreage tracked on the surveys, but they also discovered some discrepancies, including the counties in which some of the grapes were grown.



This map shows the location of Virginia's many vineyards, which plant hundreds of acres of grapes annually, almost all used for wine. NASA data helped local government officials take stock of the commonwealth's wineries and devise strategies for increasing production to meet rising consumer demand.

"If winemakers said 'I have so many acres,' they wouldn't say 'I have so many acres in this county and so many acres in that county,'" explains Annette Boyd, director of the Virginia Wine Board's marketing office. "We're getting into an additional level of detail with this data that we just didn't have with the voluntary data collection. As we go forward, it'll allow us to really perfect our measurements of Virginia vineyards."

The team also saw that certain wavelength combinations helped corroborate the presence of mature grapevines but found that an automated approach to classification of grape plots using Landsat imagery would require further research.

Benefits

Figuring out how many acres across a single state are dedicated to growing grapes might not seem like a big deal. But wine is becoming a massive business in Virginia, with 99 percent of the grapes grown there designated for wine production.

And still, Boyd says, consumer demand for Virginia wine is actually outpacing production, so there is currently a push to get more farmers interested in growing grapes and to get landowners to consider growing grapes on land they're not using. Such a boon would further diversify Virginia's agricultural economy, historically known for ham, peanuts, and tobacco, while also boosting the profile of wines already made there.

Karen Jackson, Virginia's secretary of technology, says using satellite data to benefit vintners just makes sense. "Government is not flush with cash, as much as people like to think it is, and we're not deep of bench when it comes to people. Plus, it's a resource that tax dollars have already paid for. Why shouldn't the state leverage those? I think that's good government."

Boyd points out that the full potential of using Landsat imagery to help grape growers hasn't yet been tapped. Future surveys might use the imagery to map pesticide use and to monitor heat, one of the key factors behind the ripening of the fruit. "Those measurements—temperatures, along with soil content and moisture, rainfall, and altitude—will help us in the future to identify which sites are good for growing the crop and which aren't," she says. Satellite views can also provide a sufficiently detailed picture that allows farmers to assess the health of individual rows of vines in their fields. Currently, many wineries hire videographers to capture these views using planes, but satellite imagery could provide the same function at a fraction of the cost.

DEVELOP's use of Landsat and Google Earth data to help pinpoint vineyard locations is "a testament to the fact that technology is being integrated into everything," says Jackson. "We're empowering other people to do good things, and that's what technology is for."

She adds, "For NASA to have something like the DEVELOP Program that's available and reachable, I think the biggest problem is that not enough people know about the program. It really has the capability to change industries and move economies along." ❖

Shown in the background is a vineyard in Virginia's Blue Ridge Mountains. NASA data revealed exactly where wineries were located and also yielded information that could be used to monitor the health of the crops in the future (inset).

Carbon Nanotube Resin Shores Up Boats, Bikes

NASA Technology

At 100 times the strength of steel and just one-sixth the weight, it is easy to see why engineers, and not just at NASA, were immediately excited by the potential in carbon nanotubes. But the nano-scale material was challenging to work with, and NASA funding was instrumental in helping move forward the early research needed to put it to good use.

Carbon nanotubes, made from flat carbon sheets that roll up on themselves into a tube, were first discovered by a Japanese scientist in 1991. "The theory has always been, if you can take these extremely strong particles and incorporate them into a wide variety of materials, then you can impart their strength onto those other materials," explains Zyvex Technologies President Lance Criscuolo.

But it proved difficult. "If you take raw carbon nanotubes and try to put them into a composite, they just all clump up together. Think of it as a poorly made cake batter. You've got lumps of stuff in there," he says. Many researchers were working on how to make a useful material out of carbon nanotubes, and NASA, always interested in ways to make their spacecraft stronger and lighter, put out a call for proposals.

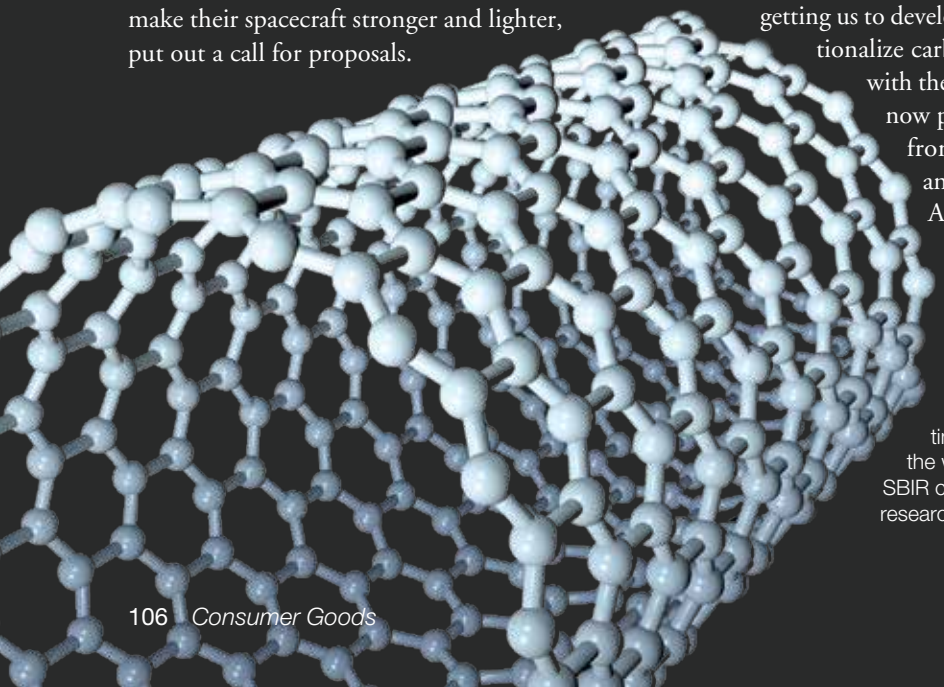
"We were looking for different ideas that people had to use carbon nanotubes, through the SBIR [Small Business Innovation Research] program," explains Brad Files, who now manages the International Space Station Research Planning office for NASA, "and one of the proposals that came in was from Zyvex."

Technology Transfer

NASA funded four SBIR contracts with Zyvex between 2003 and 2006. The first two centered on how to incorporate carbon nanotubes into a functional material and the later ones on using that material in a composite as a lightweight radiation shield. Zyvex researchers devised a polymer that transformed the properties of carbon nanotubes so they would disperse in a resin, which could then be used to reinforce woven carbon-fiber materials. Working with NASA, they were able to achieve high concentrations of carbon nanotubes with excellent dispersion in resins, including epoxy.

"Working with NASA helped guide us in the best methods in how to do that," Criscuolo explains.

"Funding from NASA was really key and important in getting us to develop the technology so that we could functionalize carbon nanotubes and get good properties with the host matrix," emphasizes John Randall, now president of Zyvex Labs, which spun off from Zyvex Corporation in 2007. "That and follow-up funding with the Defense Advanced Research Projects Agency was absolutely essential to developing the technology that Zyvex is now marketing."



Carbon nanotubes, made from flat carbon sheets that roll up on into a tube, offer 100 times the strength of steel at just one-sixth the weight. NASA funding, including several SBIR contracts with Zyvex, helped advance early research to put the material to good use.

Benefits

Often, there's a trade-off between toughness and stiffness: things that are very strong tend to be brittle, like glass, while things that are resilient aren't stiff, like rubber.

Carbon nanotube-infused resin helps make already-strong carbon-fiber composites significantly tougher without compromising the stiffness, often actually increasing the stiffness, says Criscuolo. Adding carbon nanotubes to the resin also helps the material withstand surface abrasion, so surfaces don't wear away as quickly, and it helps divert energy into the fibers, which are stronger than the resin.

"You've got all these tiny nanotubes, which are long and thin, scattered randomly through the resin. When a composite starts to fail from a fracture, it'll take a path of least resistance—and the path to failure gets much longer when it has to go around the carbon nanotubes." he says. "That's how you get a much tougher composite."

Almost immediately after the SBIR contracts, Zyvex found customers among makers of sporting goods like baseball bats and bicycles (*Spinoff* 2007), enticed by the combination of tougher, stronger, and lighter.

Since then, the company has increased its product line dramatically. It now offers six different formulations of its carbon-nanotube additive, under the ZNT product name, to be added to different resins by the customer. The company also offers its own line of composites, under the Arovex product name, in which carbon fiber, glass fiber, and other materials are pre-treated with a carbon-nanotube-infused epoxy.

While some industries, including aerospace and marine customers, have been slower to adopt the new materials, Randall says they too are coming on board. "It's always been difficult to get new structural materials, especially into aerospace—but that's understandable. You're extremely cautious when you add a primary structure to something that flies around with people in it in the sky," he says.

One of Zyvex's latest customers is using the material for ship landing decks designed to allow smaller boats to drive onto them. "The landing areas needed to be a lot tougher, because the smaller boats would still have propellers spinning when they arrived, tearing up the deck of the other boat," explains Criscuolo. "Rather than making the composite at the bottom of the boat a lot thicker and heavier, they switched to our material: it got a lot tougher without adding to the weight. "

Criscuolo says Zyvex is also using the same technology developed under the NASA program to incorporate carbon nanotubes into rubbers and other flexible materials, for applications like tires, seals and gaskets, and o-rings. "And then we've also taken that same technology and are migrating it into thermoplastics that we're starting to look into putting into medical devices."

For instance, Zyvex has partnered with a medical device company on a National Institutes of Health grant to develop a balloon catheter for insertion into arteries to help clear blockages. "The nanotubes would add additional burst strength, because these catheters are extremely thin," Criscuolo says.

One of Zyvex's latest customers is using the material for ship landing decks designed to allow smaller boats to drive onto them—sometimes with propellers still spinning. The carbon-nanotube-reinforced composite is tough enough that it doesn't get torn up, without adding extra weight.

"The NASA partnership definitely helped accelerate our ability to get into commercial applications on a much shorter timeline," he recalls.

From NASA's perspective, says Files, the collaboration was extremely successful. Although the applications for NASA's space program weren't immediately realized, he says, it is extremely important to see the results bear fruit in the commercial world.

"In the early days of nanotechnology, everybody was pushing it forward together. We didn't know which would benefit NASA, which would benefit industry or other Government agencies. Zyvex was able to take something that they were working on for us, but then use it in the commercial world. NASA is always looking for those types of technologies." ❖

Special composite materials, reinforced with a carbon-nanotube-infused epoxy, make for very light, extremely tough race cars, better able to withstand the forces of a crash. The material has also been used on sporting goods, including bicycles and baseball bats.

Energy and Environment

With eyes on Earth through more than two dozen satellites, plus a range of ground-based observation missions, NASA keeps close watch on our ever-changing planet. These scientific data have found numerous applications among public and private initiatives, including software tools that spot rainforest wildfires and monitor agricultural water use. The Agency has also transferred technology to industry, leading to self-driving farm equipment, improved fertilizers, new mineral analyzers, and much more.

GPS Correction Technology Lets Tractors Drive Themselves

NASA Technology

There has been much talk of self-driving cars lately, as various automakers and technology companies such as Google race to put the first fully autonomous vehicle on the road. But in farm fields, where driving is more loosely regulated, farmers have enjoyed self-driving tractors for more than a decade, in part due to a partnership between John Deere and NASA's Jet Propulsion Laboratory (JPL).

The Global Positioning System (GPS) was still new in the mid-1990s when John Deere, based in Moline, Illinois, started using it to enable precision agriculture.

Working primarily with NavCom, which the company later purchased, John Deere engineers began developing GPS receivers that enabled capabilities such as yield mapping, which incorporates mass flow and moisture data from sensors on a harvesting combine with GPS location data to determine how much of the harvest is coming from each part of the field. Such information can help farmers allocate future resources and determine which hybrids and management practices are the most productive.

The challenge was that uncorrected GPS can be off by up to around 30 feet due to data errors, drift in the GPS satellites' internal clocks, and inaccurate orbital parameters. What the company ultimately wanted was a system that could correct the signals with a high enough accuracy that GPS could be used to actually guide the tractor.

Meanwhile, scientists at JPL, where the first global tracking system for GPS satellites had already been developed, were working to stream satellite tracking data in real time via the Internet, rather than collecting it intermittently by phone lines. A major infusion of research and development funding from the Federal Aviation Administration, which wanted to provide pilots with reliable GPS data, enabled them to develop the necessary software, says Yoaz Bar-Sever, who was supervisor of the Orbiter and Radiometric Systems group at JPL at the time.

The result was the Real-Time GIPSY (RTG) software. GIPSY refers to the GNSS-Inferred Positioning System, wherein GNSS stands for Global Navigation Satellite System. One of the world's more complicated acronyms, RTG also ended up being one of NASA's most important contributions to modern society, enabling highly accurate GPS navigation anywhere on the planet.

"Once we were able to demonstrate real-time tracking on a global scale together with real-time data processing, it represented a breakthrough capability, and we were approached by many companies," Bar-Sever recalls. One of those was John Deere.

By this time, in late 2000, the company had just introduced its StarFire GPS receiver, which was capable of accuracy down to about six inches.

Technology Transfer

A number of companies purchased—and continue to purchase—the real-time satellite clock and orbit corrections RTG produces, but in 2001 NavCom licensed the RTG software itself and also contracted with JPL to receive data from the center's global network of reference stations.

While it was testing the JPL-based system in the field, the company continued to work on its own technology for correcting GPS signals and released its first GPS-based guidance system for tractors in 2002. The system, known as AutoTrac, was initially available only in North America and Australia, with Europe following shortly thereafter. By the following year, John Deere had begun developing a highly accurate self-guidance system based on a technique known as real-time kinematics (RTK).

While it was accurate down to about an inch, the RTK-based navigation system wasn't entirely reliable, as its radio signal could go down or be lost behind a hill, says Terry Pickett, currently manager of the Advanced Engineering group at John Deere Intelligent Solutions Group. Moreover,

A long partnership with the Jet Propulsion Laboratory helped John Deere spread self-driving tractor capabilities all over the world, lowering costs and improving yields for farmers while popularizing the idea of precision agriculture.

it was expensive and required the purchase of one or more signal towers.

By 2004, the company officially released the first StarFire receivers to tap into NASA's global network of ground stations and incorporate JPL's software, which it licensed. "John Deere based their system on our technology lock, stock, and barrel," Bar-Sever says, noting that the agreement also allowed JPL to use John Deere's GPS reference stations. "We linked our systems quite tightly."

"It was a great springboard for going from a more U.S.-based system to a global system," says Steve Wilson, who joined NavCom as the GNSS product manager in 2002, noting that engineers at the company and JPL worked together to improve the software. "In the early years, it was a team effort to have the network up and running and data flowing in."

The system was accurate down to four inches, which was a significant improvement to AutoTrac. More importantly, with this solution, John Deere could finally offer self-driving agricultural equipment to its customers worldwide.

Benefits

"That allowed us to get machines in the field all over the world that would guide themselves with a lot less overlap, and that meant a lot to our customers," Pickett says.

Typically, when a farmer crisscrosses a field pulling a seeder, plow, or other equipment behind the tractor, the rows that are created overlap by about 10 percent, Pickett explains. This means a significant portion of the field receives double the necessary seed, fertilizer, and pesticide, and the job also takes longer than necessary.

Eliminating overlap also cuts down on fuel costs, wear and tear on the machinery, and the time for which a farm had to pay a tractor operator. (An operator is still required in the cab to monitor operating conditions and avoid collisions.) And higher accuracy means more reliable yield maps.

The RTG-based system was more affordable than RTK-enabled guidance, but it could also be coupled with John Deere's RTK solution for a feature called RTKX. Available for AutoTrac, RTKX relied on the low drift of the corrected GPS signal to extend RTK-quality accuracy for up to 15 minutes whenever the RTK radio link was lost, a common occurrence in the hills of many farming areas.

Another feature introduced in 2004 was Swath-Control Pro, which allowed a sprayer or spreader, and eventually planters, to turn off parts of the equipment overlapping areas that already had fertilizer, pesticides or seed applied, eliminating overlap entirely. The second-generation StarFire receiver enabled the iTEC-Pro capability, which the company released in 2007. This allowed a tractor to finish a row, lift the equipment it was pulling, turn around, and pick up exactly where it left off, all with no input from the driver.

"Self-guidance had a big impact on the cost of the product farmers were producing, the amount, and often the quality," Pickett says, adding that AutoTrac was shown in several university trials to save producers on the order of 15–20 percent through efficiency and reduced input costs. In addition, many customers claim to gain improvements in yield of up to 10–15 percent by better management techniques enabled by yield mapping and analytics used with that data.

For more than a decade, John Deere's StarFire GPS receivers used NASA's global network of ground stations and the JPL software, which the company licensed, to enable self-guided tractors.

Among other benefits, accurate GPS helps farmers manage their fields, for example enabling more accurate observations and crop mapping.

All the while, John Deere was perfecting its own means of precision guidance, and the company let the NASA license expire in 2015, now relying on its own system.

By 2015, he estimates, 60–70 percent of the crop acreage in North America was being farmed using self-guidance systems, as was 30–50 percent of the farmland in Europe and South America and more than 90 percent of Australian farmland.

But Pickett says the accuracy that originally came from the company's partnership with JPL not only gave rise to significant improvements to John Deere's guidance technology but also served to help popularize the notion of precision agriculture. "Guidance was what drove it, and what drove guidance was accuracy," he says.

Wilson notes that StarFire receivers became more accurate than the GPS on a military fighter jet. "Yoaz and his team know what they're doing, and we were able to leverage what they'd developed and provide a very good service," he says. ❖

Controlled-Release Fertilizer Takes Root in Fields, Groves Worldwide

NASA astronaut Steve Swanson harvests red romaine lettuce on the ISS, the first fresh produce grown and eaten in space. The Veggie project, which is ongoing, uses Florikan's controlled-release fertilizer to nourish the growing plants.

NASA Technology

Astronaut ice cream may be an exotic treat for kids, but for real space explorers, it turns out a fresh, crunchy salad could sometimes really hit the spot. The ability to grow food in space could also prove crucial for longer-duration voyages envisioned for the next decades.

Growing plants in a spaceship, and one day on another planet, is a complicated endeavor, as Gioia Massa, science team lead for the NASA Veggie project at Kennedy Space Center, will tell you. But one tool making it much easier is a specially formulated fertilizer, developed years ago with NASA help, that has also drawn huge accolades from growers on Earth.

The fertilizer, blended by Sarasota, Florida-based Florikan, is coated in polymers that control when and how much of each ingredient—macronutrients like nitrogen, phosphate, and potassium, and micronutrients like magnesium and zinc—is released over six months to a year.

"We don't use soil, because soil is very nonuniform and makes it hard to ensure a good outcome," Massa explains. Instead, the Veggie plant-growth platform aboard the International Space Station (ISS) uses a porous, baked-clay substrate. That clay holds the roots and the water in place, but it doesn't provide any nutrition for the plants—that all comes from the fertilizer.

"Having the ability to add a controlled-release fertilizer—which adds the right amount of nutrients over time without any mixing or any chemicals that you have to measure out—makes it much simpler," Massa says.

There is still research being done to optimize the fertilizer for different plant types, including modifying the blend of ingredients and release rates and examining how different fertilizers impact the nutrient content of the harvest. But using a single-application, controlled-release fertilizer means that, day-to-day, the astronauts and the Veggie research team can focus on other challenges, like how often to water the plants and how best to use lighting to promote growth.

Their efforts have already borne fruit—or, technically, leaves—with red romaine lettuce grown and eaten on the ISS in 2015, and zinnias cultivated through 2016. Future experiments are planned for 2017 and 2018 to grow dwarf tomatoes and Chinese cabbage, with a second Veggie plant-growing module to be sent up to increase the variables able to be tested.

"We're learning a lot. We've certainly had our challenges, but we've also had tremendous success," Massa says. She is excited about breaking new ground with these experiments—and confirms Florikan controlled-release fertilizer will continue to play its important role.

Technology Transfer

Florikan founder Ed Rosenthal didn't intend to push the frontiers of where plants are grown when he first began developing his award-winning fertilizer. But he saw how fertilizers, including those sold by the company he and

Here, large batches of the Florikan fertilizers await quality control testing before being bagged up and sold. The high-tech process to coat the fertilizer in a porous polymer to control how quickly the nutrients dissolve in water was perfected with help from NASA.

his wife had founded in 1982, were getting used, and saw an opportunity.

"I went to see a very good friend of mine: a PhD, who produces ornamental plants," Rosenthal recalls. "He's throwing bags of water-soluble fertilizer, must have been 40 or 50 bags, in the tank. And as I'm watching it, some is floating to the top, some is segregating to the bottom. He has to turn on an agitator just to keep the fertilizer in the solution."

Rosenthal was dismayed—if farmers were dousing their plants with this poorly mixed solution, a huge proportion of the nutrients would leach out into the groundwater. That was terrible for the environment and not very helpful for the plants.

He started studying the problem and eventually told the grower, "I believe you're wasting more than two-thirds of your nitrogen: it's going straight into the groundwater."

The segregation was occurring because different nutrients dissolved in water at different rates, and that gave Rosenthal an idea. Although not a chemist by training, by 2002 he'd spent decades working with fertilizers and

> "In a global world, it's ultimately about feeding more people in an efficient manner that is sustainable."
>
> — Jeff Roesler, J.R. Simplot

polymers at Florikan and before that at a company that manufactured polymer-based plastic plant containers.

"I wondered if I could separate each nutrient based on its relative solubility and when it was needed by the plant," he says. If he could then coat each nutrient in a different polymer, some with a larger-porosity polymer to let a lot of water in to dissolve the substrate and release the nutrient as quickly as possible, some with a smaller porosity to slow down the release, he thought he could create a fertilizer that delivered exactly the right amount of each nutrient at exactly the right stage of growing.

Florikan's clients had typically been applying fertilizer monthly. "For example a nursery with 100 acres of potted calamondin orange," would have a huge workforce applying a tablespoon per pot, 12 times a year. Rosenthal's new staged-release fertilizer would get the same results with just four tablespoons applied once a year, according to his calculations.

He brought the prototype to a leading nursery grower who was skeptical but agreed to let Rosenthal try it out on a few acres of plants. "In six months, when the grower saw our plants looked the same as the ones he had already hit with six applications, he said, 'Ed, you got any more of that stuff?'"

The new product innovation, dubbed Staged Nutrient Release (SNR), was quickly embraced by the market, and in 2004, Florikan was recognized by the state of Florida and by the National Society of Professional Engineers for making one of the year's most innovative new products. The latter award came with a special perk: 40 hours of free

“NASA’s expertise, helped us advance our development by years. We were happy to pay it back.”

— Ed Rosenthal, Florikan

Fertilizer made with Florikan’s patented formula, now owned by J.R. Simplot and sold as Gal-Xe^{ONE}, nourished this lush grass at a golf course in Arizona. J.R. Simplot was interested in the product because it was more efficient and better for the environment.

consulting with a Federal agency to take the innovation forward. Rosenthal chose NASA.

“I knew NASA was working with some space-age polymers, really sophisticated polymers that had yet to make it into the mainstream commercial field,” he says. He was connected with Kennedy researcher Chris Gilfriche in October 2005 through the Space Alliance Technology Outreach Program (SATOP).

At the end of the 40 hours, the NASA researchers recommended a whole new approach: coat the nutrients in a single, impervious polymer, and then treat them with a chemical to open up pores to the exact specifications required. That spurred two more years of lab work to perfect the formula, including a continued back-and-forth with the SATOP group. By 2008, Florikan had two new patents, one for staged nutrient-release fertilizer and another for the polymer coating it was using.

“The ornamental industry—the nursery industry producing foliage plants—was the first to embrace the change to the controlled-release fertilizer,” Rosenthal recalls, saying he soon had enough business to open a coating facility in Florida. Since then, he has sold both patents to agribusiness giant J. R. Simplot Company, which has introduced the technology across the western United States and overseas.

Image courtesy of J. R. Simplot company

Florikan retains a license in perpetuity to manufacture and sell the fertilizer in 32 eastern U.S. states, and its business has also grown in recent years, prompting a need for a brand-new 85,000 square-foot plant in Hardee County, Florida, and creating some 80 new jobs.

Rosenthal credits a huge portion of this success to the guidance he got from NASA. "For us to be able to coat the fertilizer here in Florida and introduce it into the market, that was a result of NASA's SATOP help, no doubt. It made the product commercially affordable and made us become a huge manufacturer."

Benefits

The key advantage to Florikan's staged nutrient-release fertilizer is that growers need to use far less of it, far less often than traditional formulations. That significantly reduces the harmful environmental impact of nutrient runoff, and it also means less labor and lower costs for growers.

"With fertilizer, you want to put it where you intend it to be used, because if it goes into the groundwater, it may create problems," Rosenthal explains. Nitrogen, in particular, has been linked to harmful algal blooms, which can release toxins that harm, and even kill, marine wildlife including dolphins, manatees, and sea turtles.

"If you can apply less fertilizer overall, there is less of a potential impact from all nutrients. Applying fertilizer once a year or once every six or nine months is better than every 30 days."

One of Florikan's early formulations was called Florikan Nutricote 18-6-8, for its ratio of nitrogen, phosphate, and potassium, and it was designed specifically for ornamental plants so they would get the right amount of each nutrient when they needed it without waste.

"Florikan's research for continuous improvement in controlled-release fertilizer formed the basis for the successful introduction of Nutricote in the United States," Rosenthal says. "From there, Florikan's commitment to innovative technology helped form the NASA SATOP partnerships, resulting in new polymer coatings for the custom-blended Florikan Nutricote and Florikote fertilizers and now for Simplot's patented Gal-Xe^{ONE} product line."

Every batch of Florikan coated fertilizer is tested to ensure the polymer coating allows the nutrients to dissolve at the expected rates. Small samples are placed in distilled water and held in an incubator at 100 °F for seven days. The quality control team checks the sample after one, three and seven days.

As Florikan has grown, it has expanded its offerings into other types of plants, creating special blends for citrus groves and, more recently, sugar cane, where standard practice had been to drop fertilizer from airplanes five times a year. Florikan proposed a new fertilizer that farmers could apply just once when the cane was first planted. "They're now buying significant quantities for several thousand acres. Without NASA and SATOP, none of it would have happened," Rosenthal says.

J. R. Simplot's customers include large-scale nursery and turf growers across the western United States, as well as palm oil growers in Indonesia and Malaysia. Jeff Roesler, vice president for specialty business units, says the technology highlights two of Simplot's core values: "respect for resources and spirit of innovation."

"In a global world, it's ultimately about feeding more people in an efficient manner that is sustainable," he emphasizes, saying this enhanced-efficiency fertilizer does that extremely well.

And when NASA called Florikan for help with its Veggie project, Rosenthal created a new blend for flowering plants, like the tomatoes next heading up to the ISS. The new blend, which Florikan has since also released commercially, has a 14-4-14 nutrient ratio, designed to be applied every 100 or 180 days. "If we'd talked to him ahead of time," Massa notes, "we'd probably have tested that 14-4-14 formulation for the zinnias."

"NASA's expertise helped us advance our development by years," Rosenthal emphasizes. "We were happy to pay it back." ❖

Satellite Imagery Sheds Light on Agricultural Water Use

NASA Technology

Earth may be the "Blue Planet," with more than 70 percent of its surface covered in water, but it is still a thirsty planet, with freshwater in heavy demand. The most significant draw on the water supply is crop irrigation, accounting by some measures for nearly two-thirds of U.S. surface-freshwater withdrawals.

Keeping track of just how much water gets used—and making sure it gets used efficiently and legally, where and when it's needed—across millions of acres of crop land is no easy task.

Researchers armed with data from the Landsat Earth-observing satellites recently teamed up with Google to make it a whole lot easier. The researchers from the University of Idaho, the University of Nebraska, and the Desert Research Institute are using the satellite images to map evapotranspiration—water evaporating from the ground or transpiring from the plants.

Evapotranspiration levels are a way to estimate how much water the plants are using. Some of the water vapor comes directly from the soil, but much of it passes through the plant first. "That's a necessary process," explains University of Idaho water resources engineering professor Richard Allen, "because it's that flow of water from the soil that transports the nutrients the plant needs."

To keep that process going, the area needs water, either from rain or, quite often, from irrigation. "Evaporation and transpiration together represent the total consumption of the resource," Allen says. And because both evaporation and transpiration use energy, they have a cooling effect, the same way sweating cools a person's skin.

If farmers could compare actual evapotranspiration levels with an expected or ideal level, they'd have a better idea of whether they're irrigating enough or overwatering. They could also look at evapotranspiration levels across the field to ensure they are getting uniform coverage from their sprinklers—not underwatering some spots or overwatering others.

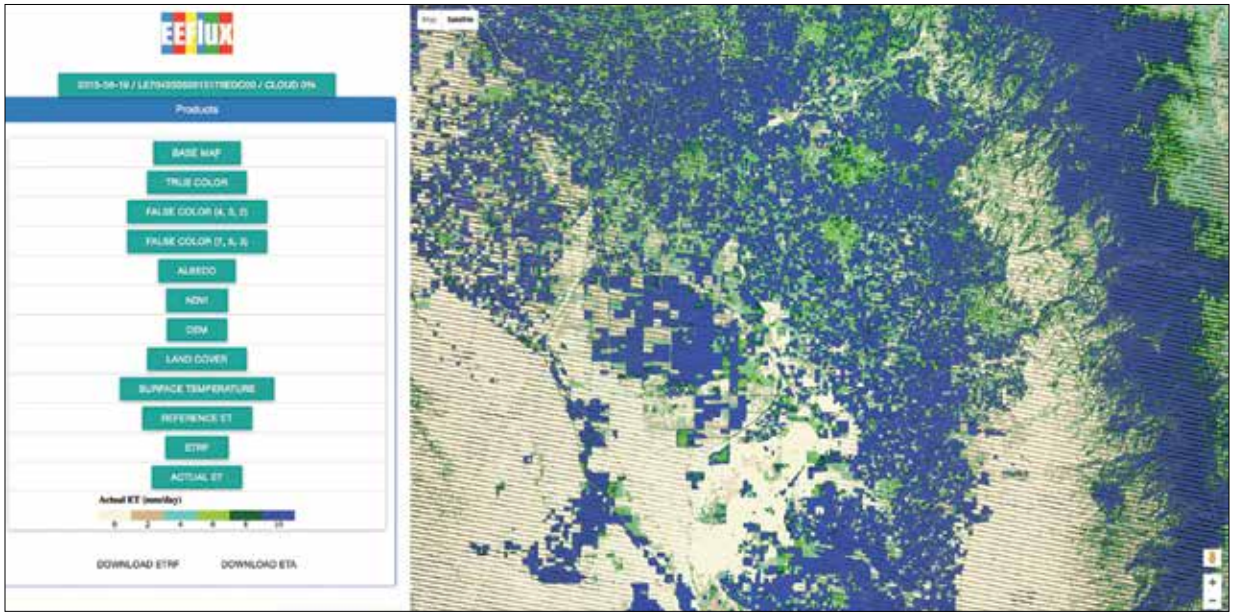
NASA launched the first Landsat satellite in July 1972 and, under U.S. Geological Survey (USGS) management, the program has been providing continuous images of Earth's surface ever since. The latest iteration, Landsat 8, was sent into orbit in February 2013 and produces high-resolution images of the entire planet every 16 days. With the help of Landsat 7, which is still in operation, full coverage is available every eight days. Both satellites carry a thermal imager that captures images in the infrared band, which shows warmer and cooler spots across Earth's surface.

Technology Transfer

Allen has been using Landsat data to study evapotranspiration since about 1999, when he was first approached by the Idaho Department of Water Resources, which had received a grant from NASA, via Raytheon Corporation, aimed at finding wider uses for the satellite data.

Allen had recently been to a conference in Europe where, among others, a Dutch researcher named Wim Bastiaanssen presented information about using evapotranspiration mapping to improve water management. Bastiaanssen had devised a model called Surface Energy Balance Algorithm for Land (SEBAL), which Allen thought he could adapt and use in Idaho.

"After about three to four years, we started evolving SEBAL to fit with our usage in the west. We named it METRIC and have been evolving it ever since," Allen says. METRIC, short for Mapping Evapotranspiration with Internalized Calibration, required downloading the massive



Using infrared imagery captured by Landsat satellites and publicly available on the Internet through Google Earth Engine, EEFlux can quickly create maps of evapotranspiration, a way to measure how much water is being used. In this map of an agricultural region in California, dark blue and dark green represent higher levels of evapotranspiration, while light brown represents low levels.

set of Landsat images to a desktop computer and calibrating them with weather-station data and other details—not something that could be easily done without training, access to powerful computers, and time.

So when Mountain View, California-based Google unveiled its Google Earth Engine in 2010, Allen and his collaborators saw an opportunity. The cloud computing platform uses Landsat data, which USGS had begun distributing free of charge, making the huge trove of information accessible worldwide.

"What Earth Engine can do is get rid of a lot of the grunt work of just downloading and storing data. That can take up a significant amount of time for any researcher," explains Google Earth Engine developer advocate Tyler Erickson.

Allen, alongside Ayse Kilic from the University of Nebraska and Justin Huntington of the Desert Research Institute and with input and guidance from Google's team, led the effort to modify the METRIC algorithm to work with Earth Engine, creating Earth Engine Evapotranspiration Flux (EEFlux). Now anyone with access to the Internet can access the Landsat data, choose a location, and see an evapotranspiration map within seconds.

Benefits

"We are very happy that they are making an application that will reach a wider net of users, rather than just their own research group," Erickson enthuses.

Early users of EEFlux include the California Department of Water Resources, the California Water Control Board, and the World Bank, and the researchers expect to expand its use more widely as the program completes beta testing. They are also still fleshing out the application so it can fill the gaps between satellite snapshots and reflect the total depletion of water over the course of a growing season, Allen says. This is something he can do with METRIC, but it hasn't been adapted to Earth Engine yet.

The program is most useful for "groups of water users that need to be managing the water resources as a unit, because they're impacting groundwater pumping," he explains. "They need to know who's pumping, is it sustainable? What are we going to do about getting extraction in line with sustainable recharge?"

EEFlux is already being used by the California Department of Water Resources, the California Water Control Board, and the World Bank, and the researchers expect to expand its use more widely as the program completes beta testing. The program helps water managers know who is pumping water, how much, and if the current usage is sustainable.

And when water management agencies are creating plans to improve irrigation efficiency or evaluating proposed transfers of water rights between farmers and cities, they also need data. "They often have questions like: 'How much water is actually saved?' and 'Is the new crop using more or less water than had been consumed in the past?'" Huntington explains. "With METRIC and EEFlux applications, detailed answers can be obtained quickly."

The algorithm is also helpful in alerting to early signs of drought, notes Kilic. Previously, water-monitoring groups would use vegetation indices, which look at the health of plants, to pick up signs of a drought. "But that doesn't pick up the drought immediately," she says. "We prefer an evapotranspiration, or ET, drought index, which is satellite-based, and it really picks up that drought signature immediately."

Allen explains, "That field may still look green, but if it's stressed because the soil is dry, it's going to reduce its ET and reduce its yield."

Beyond water management agencies, he adds, "we want to get this in the hands of the individual farmers."

"They're already doing precision agriculture," choosing carefully how best to irrigate fields, Kilic says, especially in states with limited water supply. "Now let's say there's a lower yield in one part of the field, what is the cause? Is it because of the irrigation practices? They can see that from their water consumption map. Having this data will allow them to spot the problem immediately."

Currently, the main avenue for gathering water consumption information across large farms is to send airborne drones to take pictures, she says. A free, web-based system that uses satellite data stands to save a lot of money, either for the company providing that information on a consultant basis for the farmers or for the farmers themselves.

But none of it would have been possible without the thermal infrared images taken by the satellites NASA put into orbit, something, Allen notes, that almost didn't happen at all, because plans for Landsat 8 initially didn't include a thermal imager.

"The water resources communities all through the United States, especially in the irrigated areas, are very appreciative that NASA put the thermal imager on Landsat 8 and that future Landsats are guaranteed to include a thermal imager," he says. ❖

Building Sensor Monitors Power Usage, Device by Device

NASA Technology

When NASA wanted to build the greenest, most energy-efficient Federal building in the United States, it needed a way to keep track of the energy being consumed. After all, good design is only the first step—at a certain point, people were going to be using the space.

Architects designed the newest building at Ames Research Center, dubbed Sustainability Base, to reduce as much as possible the energy its occupants need. For instance, it includes massive windows and skylights, with all structural load carried by external supports rather than by light-blocking pillars. That way, occupants in the 50,000-square-foot space have less need for artificial light during daylight hours.

In April 2012, thanks to its environmentally conscious design, Sustainability Base received a Leadership in Energy and Environmental Design, or LEED, Platinum certification by the U.S. Green Building Council—the highest-level certification it offers. It was the first newly constructed Federal building to receive the rating.

But NASA didn't want to stop there, explains Sustainability Base research lead Rodney Martin. It wanted to ensure that, even after construction was complete, the occupants were making the best use of energy on a day-to-day basis—and to do that, Sustainability Base needed a mechanism to monitor energy consumption. It's fairly easy to know how much energy an entire building is using, explains Martin, "but that doesn't give individual occupants much info on what they can do to reduce that number.

"We need ground truth. What's consuming the most energy?" Martin says.

NASA built Sustainability Base at Ames Research Center to be the most energy-efficient building possible—but the work didn't stop when construction did. The project uses Verdigris sensors to help learn more about how the people in the building use, and save, energy.

Technology Transfer

Enter Verdigris Technologies Inc.: the Moffett Field, California-based company designed a sensor that "listens" to electronic signals as they pass through a circuit panel and analyzes their fluctuations using a deep packet inspection algorithm—the same technology the National Security Agency uses to monitor text messages between suspected terrorists.

The algorithm allows the sensor to differentiate between the devices using electricity in the building. So if you plug in an iPhone charger, it'll know. And if your refrigerator has been chugging along using a certain amount of power every week and suddenly that number starts growing, it'll know that too.

Similarly if, like company cofounder Mark Chung, you go on vacation but your pool pump motor gets stuck in the "on" position, you'll find out about it before you come home to a massive electricity bill. Chung, frustrated by the inexplicable electricity spike and the cumbersome and inaccurate tools available to help him identify the problem, was determined to create a better solution.

The electrical engineer and his colleague, Jonathan Chu, also an engineer, had been working with deep packet inspection algorithms to help telecommunication companies differentiate between types of data being transmitted. Some, like text messages, need to be extremely accurate but could stand a short delay. Others, like voice calls, need to be sent

in real time, even if they end up slightly garbled. "Using deep packet inspection algorithms, the network is able to detect the different type of packets and develop priority routing schemes," Chung explained.

Chung and Chu used the same method when they designed their electricity sensor. "We thought we'd run deep packet inspection and see if we can pick up the big thing," Chung recalls. "And the surprise was, 'Oh, I can pick up a lot of things.'"

When Verdigris approached NASA about a potential research partnership, they were put in touch with the team at Sustainability Base, who decided to incorporate a pilot system based on Verdigris' early prototypes. The company entered into a nonreimbursable Space Act Agreement with NASA, a decision, Chung says, that launched the start-up into the big time.

"We started to work with them to find a path to develop our sensor technology and for NASA to work on validating whether what we were predicting with our algorithm was true," he explains. "We'd been doing that in our lab with 15 or 20 devices, and suddenly we were in a wing of the building with hundreds of thousands of devices, in a real-world setting."

That was a crucial step in developing the device for the market, Chung says. "With our system, the first time you plug it in, it can differentiate between devices, but you have to teach it what they are. That was one of the big advantages of working with NASA: Sustainability Base was like a virtual playground for us to teach the system.

"It absolutely got us going faster than we would have otherwise," Chung emphasizes, noting that, "working with NASA also extended some credibility to us. It opened the doors for conversations with other customers."

Benefits

The Verdigris system continuously monitors electricity consumption and sends alerts when there are problems, whether lights are turning on automatically when no one is around or a machine is no longer working the way it should and could be heading toward a breakdown.

The latter is something that could prove extremely useful for NASA beyond Sustainability Base, says Rosalind Grymes, deputy director of the partnership directorate at Ames Research Center.

Not only could a Verdigris sensor help mission scientists design equipment that optimizes energy use, she says, but it could also predict when a failure is about to happen. In the case of a robot on Mars, where repairing the instrument

Verdigris sensors plug directly into the circuit panel and are able to monitor just how much energy is being consumed by which device, even when the circuit contains multiple devices. The system generates automatic reports than can be emailed or checked right on a smartphone.

“Working with NASA also extended some **credibility to us.** It opened **the doors** for **conversations** with other **customers.”**

— Mark Chung, Verdigris Technologies Inc.

Verdigris sensors at a Marriott Marquis hotel in Washington, DC, seen here lit for the evening, helped building managers realize that lights in several ballrooms were being automatically turned on every night between midnight and six in the morning, even though the rooms were empty. They were able to fix the faulty programming, saving electricity and wasted lamp light for the bulbs.

is often impossible, that kind of information could be game-changing.

"When you have advance notice, you may be able to isolate a device, so it doesn't bring down other devices. You may be able to make remote changes that prevent the failure," she says.

And if you can't do anything? Well, at least you'd still have time. "You can now optimize the use of that device from now until the predicted failure, so you can get the best science out of the remainder of its life," she says.

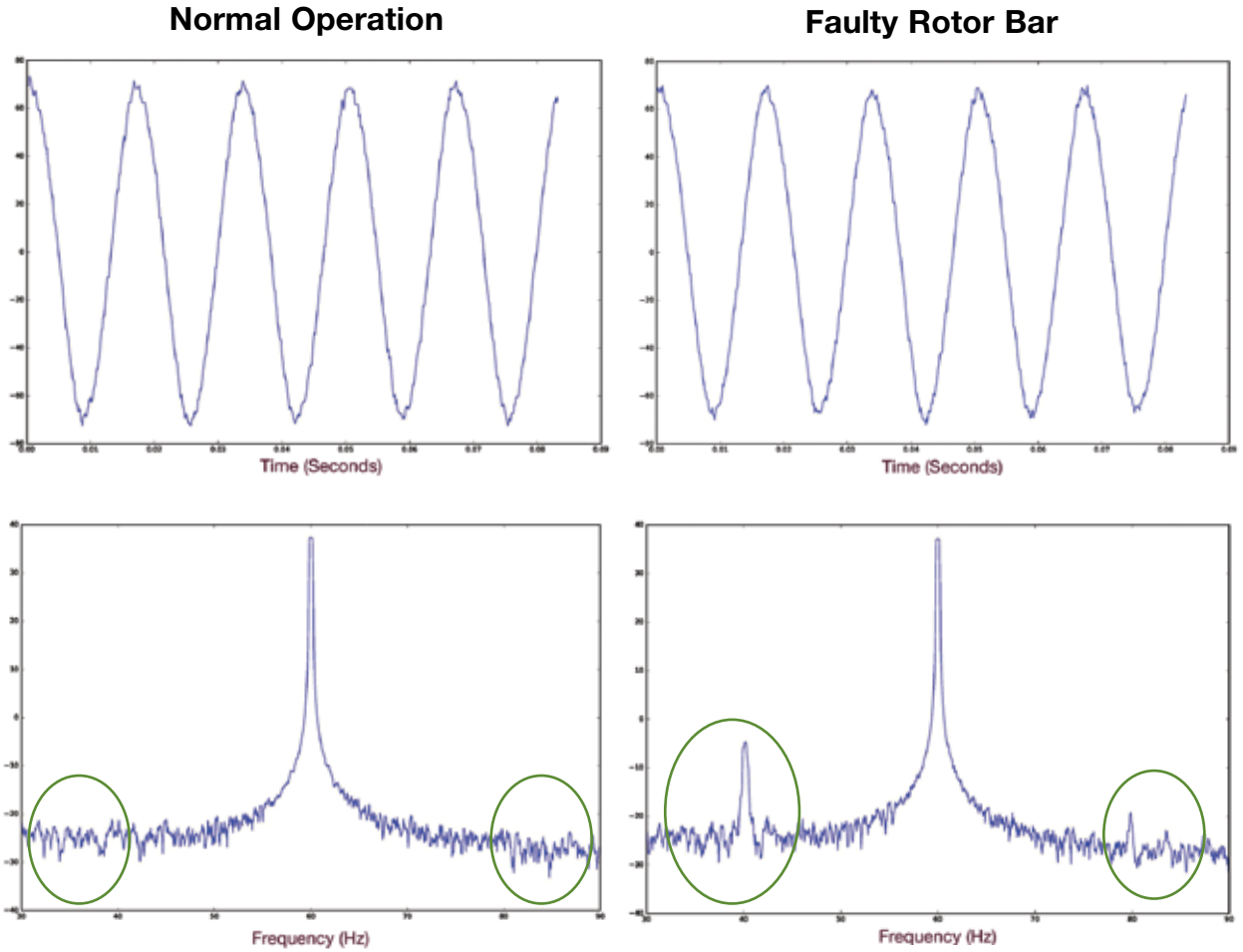
That function has proven to be a big selling point for Verdigris' commercial customers, which include major hotels, corporate offices, hospitals, and manufacturers. Once installed in a building, the information gathered by the sensor is sent to the managers in weekly emailed reports and can be monitored by smartphone or on the Web.

The information is also compared to data gathered by Verdigris sensors at other sites and stored in the cloud, increasing the data points included in the baseline. "One example, at a San Francisco hotel, was that we found dishwasher equipment not going through its heat cycle properly," recalls Chung. The system was able to identify the problem because the dishwasher wasn't using as much power as expected to reach the heat needed to properly sanitize the dishes.

"They wouldn't have caught this through their normal inspection process," he says, which means that, without the Verdigris system, the hotel may not have realized there was a problem until guests got sick.

"That was a good demonstration of the kind of device that NASA is also so critically interested in," Grymes added. "We don't want to wait for a device to fail, because the consequence is a really bad day in space." ❖

Detecting Motor Faults



The Verdigris sensor and algorithm are also able to alert users to anomalies that might mean a device is not operating as it should. In this case, the motor current at startup looks fine, but another analysis of the frequency spectrum suggests a magnetic rotor bar is not working correctly.

Earth Observation Spots, Helps Prevent Rainforest Fires

NASA Technology

Since the launch of the first Landsat satellite in 1972, NASA's observations of Earth from space have famously been used for charting trends in climate, land cover, weather patterns, and other Earth systems. The Space Agency has put countless downward-looking satellites into orbit to observe everything from ice and forest cover to ocean levels, soil and atmospheric moisture, gravity field fluctuations, and much more. But NASA's many Earth-observing missions have another use as well: spotting events of interest, such as wildfires, in remote areas.

With about two dozen satellites currently charting and recharting the planet's 196.9 million square miles of surface, the Agency is constantly working to enhance software to manage that ever-growing mountain of data and find new ways to make use of it.

In 2010, NASA launched the NASA Earth Exchange (NEX) project to leverage the supercomputing facility at Ames Research Center to enhance scientists' ability to rapidly analyze nearly a petabyte of Earth-observation data. To ensure the information is used not only for research but also to achieve societal benefits, the Agency's Applied Sciences Program, part of its Earth Science Division, supports partnerships through NASA's annual Research Opportunities in Space and Earth Sciences (ROSES) solicitation. The program calls for proposals to use Earth-observation data and models to inform management, business, and policy decisions on several subjects, including wildfires and other natural disasters, with selected proposals funded through ROSES.

Technology Transfer

Both ROSES and NEX have contributed to efforts by the nonprofit environmental organization Conservation International, based in Arlington, Virginia, to prevent deforestation and degradation from fires in tropical forests. In 2012, the organization was granted ROSES funding to overhaul and update its fire-monitoring and early warning systems and integrate data from recently launched NASA satellites. The organization's fire-risk model had originated with a NASA grant about a decade earlier, and it would now benefit from an upgrade and expansion enabled by the climate data and supercomputing resources available through NEX. Using NEX to update fire-risk models and prototype and test the integration of data from additional NASA satellites, Conservation International developed an improved fire detection, monitoring, and risk forecasting system now known as Firecast.

Karyn Tabor, Conservation International's principal investigator for the upgrade, previously ran the organization's fire-risk system, which in 2012 was only providing data for the Bolivian Amazon. The expansion to cover nine more countries would require computing resources the organization does not have in-house.

Tabor already knew Forrest Melton, senior research scientist at California State University, Monterey Bay, as they had worked together before on an Applied Sciences Program proposal. The university is a partner in Ames' 10-

Members of the Friends of Nature Foundation in Bolivia adjust a fire risk indicator for the day. Daily and seasonal fire risks are among the products Conservation International's Firecast system offers.

year Cooperative Agreement for Research in Earth Science and Technology with various Earth science institutions, and Melton was using NEX to map California's Central Valley and determine the effects of drought on agriculture. He became a co-investigator on the Firecast project.

"Our goal was to help Conservation International use the supercomputing resources and Earth-observation data available through the NASA Earth Exchange," Melton says. "The issue when you're developing a new model or application is that you can spend months pulling together and processing all the datasets." NEX had more than 800 terabytes of data that Conservation International could use to develop and prototype its new fire-risk forecast model and decision support system.

With far more computing and storage space than Conservation International had on its server, NEX let Tabor not only overhaul the fire-risk forecasting system but also expand it from Bolivia to include Colombia, Peru, Venezuela, Ecuador, Guyana, Suriname, Paraguay, Madagascar, and Indonesia. Conservation International has field offices in seven of the nine countries. Once the expanded prototype was developed and tested on NEX, it was moved to a production server on the Amazon Web Services Elastic Compute Cloud platform.

In addition to daily fire-risk forecasts, the system also now incorporates seasonal risk forecasts for Peru and Bolivia from NASA's Goddard Space Flight Center, calculated several months before the fire season, based on Atlantic Ocean surface temperatures.

To augment the fire-alert system, which is still housed on Conservation International's server, Melton also advised Tabor on systems for incorporating information generated by users on the ground via mobile devices. He had experimented with such systems to validate satellite information for his drought-impact mapping in California. "We were trying to figure out how we would use mobile devices to collect validation of fire alerts and enable access to a mobile platform for users to log patrolling information," Tabor says.

Image courtesy of Thomas Muller

Park rangers patrol the Alto Mayo protected forest in Peru. There and in Madagascar, Conservation International is incorporating the OnSight platform, which GeoVisual Analytics created with NASA funding, into Firecast. OnSight lets patrollers on the ground make observations to validate and augment fire data from satellites.

Smoke from forest fires in Indonesia can be seen in an aerial image from NASA's Fire Information for Resource Management System. Conservation International's Firecast system uses imagery and data from a number of NASA satellites for both spotting and forecasting rainforest wildfires. Satellite data is just one of NASA's several contributions to the system.

The team settled on the OnSight platform that GeoVisual Analytics, a company specializing in analysis of Earth-imaging data, had developed under two Small Business Innovation Research contracts with NASA's Stennis Space Center. OnSight crowdsources information from users in the field, who can upload photos and other data about events they observe.

The preexisting fire-risk and fire-alert systems were based on imaging data from NASA's Moderate Resolution Imaging Spectroradiometers (MODIS) aboard the Agency's Terra and Aqua satellites, as well as the Tropical Rainfall Measuring Mission, a joint NASA and the Japanese Aerospace Exploration Agency (JAXA) mission. As a result of the update, the fire-risk system also now incorporates data from the Ground Precipitation Mission, which flies on the Core Observatory satellite built by NASA and JAXA. In addition, the fire alerts include higher-resolution, higher-accuracy active fire detection from the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-Orbiting Partnership weather satellite, a joint project between NASA and the National Oceanic and Atmospheric Administration.

While the risk and alert systems remain on separate servers, they're now accessed as a single Firecast product through a single website. "We always had these separate systems, but the key now is that there's one website, and on the front end they look like they're in the same place and target a broader user base," Tabor says.

Benefits

The main purposes of Firecast are to spot and stop illegal activities like slash-and-burn operations in protected areas and to let people know when legal burning activities shouldn't be carried out due to high fire risk.

Tropical forest fires cause 7–12 percent of global greenhouse gas emissions, and fires are the main tool used to clear forests in the tropics. These biodiverse ecosystems are not only critical to mitigating global climate change, but they also provide essential resources for people, such as freshwater, food, and medicines, in addition to supplying habitat for the some of the most endangered species on Earth.

Tabor says Firecast packages and delivers the information in a way that's as useful and user-friendly as possible in each area it serves. Users—typically government offices, conservation groups, forest services, and academics—are asked what challenges they face and how they want to use the tool, and then data from locally trusted sources is presented in the local language, in the requested formats, and in the context of different areas' historical data. "We build the system together with the end-users, so they have an invested interest in it," Tabor says.

While there are existing global fire alert services offering some of the same functions, she says, "what we try to do is provide an extra layer of customization to meet the users' needs."

"Karyn's is an international-scale project that truly serves local communities," says Amber Soja, a scientist at NASA's Langley Research Center and an associate program manager for wildland fires and disasters under the Applied Sciences Program, who manages the partnership with Conservation International. "She works with countries that have extremely limited access to information and data and helps them fill a critical information gap."

Tabor says a big part of the work is teaching people how to use Earth-observation data and where they can find it, whether through Firecast or elsewhere. Recently she has forged a partnership between Conservation International and NASA's Applied Remote Sensing Training (ARSET) program to build the capacity of conservationists worldwide to use Earth-observation data and tools.

Firecast is in various stages of maturity in different countries, she says, noting that the highest use of risk forecast data is in Bolivia, where it has been used the longest and where a local partner organization works directly with indigenous and Mennonite farmers. "The key there is that we don't want fires to spread into a forest or even spread and damage farmers' property."

Seasonal forecasts, which are produced annually, only recently became available to partner countries in South

America, and Tabor says she hopes governments can use them to allocate money in advance for fire prevention and firefighting.

In fall of 2015, Peru became the first country with the OnSight application as part of Firecast, although it didn't go into use until the following summer, allowing users to upload and share information. Managers of protected areas can use it to investigate fires and plan patrols. The application was rolled out in Madagascar in June 2016.

Conservation International was already providing VIIRS data to leaders in Madagascar, and the larger Firecast program had launched there in summer of 2015.

Already, people have been caught burning on protected land as a result of the program, Soja notes. "When people get caught, everyone knows it, and then they make better decisions," she says. "Now everybody has the data in near-real time."

In the near future, Tabor plans to incorporate a product another group is developing based on Landsat active fire data to increase the spatial accuracy and sensitivity of fire detections. In addition, she plans on reaching new user audiences by helping companies make sourcing decisions based on long-term trends. For example, Conservation International partners with major corporations that purchase carbon credits or have signed net-zero deforestation agreements. "This would be looking at where they're getting their products and making sure they're not causing deforestation. And if they are, where can they offset it with reforestation?"

Firecast's ROSES funding will run out in a year or so, but by then, Tabor says, the updated systems will be in place, and other funding will keep the system operational. "If you want to make a big change, you've got to get the money to do it, and that's where the support from NASA was so valuable," she explains. "The systems are cheap to operate, so we don't need a lot of money to keep these things going."

Tabor says she's worked with NASA on various projects since she completed an internship at Goddard, where her graduate school advisor had worked. "I've maintained close ties with people I met there and others I've met," she says, noting that she's currently working on another proposal for a NASA partnership. "It's just kind of the circle I run in, is the NASA circle. I like to think I bridge the international conservation community and Earth-observation community to communicate the needs of each and make connections where I see opportunities for both to benefit." ❖

"When people get caught, everyone knows it, **and then** they make **better decisions."**

— Amber Soja, Langley Research Center

Droughts, slash-and-burn operations, and even legal burning on risky days pose increasing fire risks to rainforests around the world. Conservation International's Firecast system, enabled by a number of NASA partnerships, tries to minimize those risks.

Image courtesy of Art Wolfe

Mineral Analyzer Shakes Answers Out of Soil and Rocks

NASA Technology

How do you search for signs of life on a planet you've never been to? If you're NASA, you send robots to do your dirty work, sifting through the soil and rocks for clues. The tools sent with those robots need to be hardy and maintenance-free—qualities that make them appealing here on Earth as well.

On the Curiosity rover, a tool called CheMin—short for Chemistry and Mineralogy—is helping scientists determine just what minerals make up the Martian landscape and whether organisms, single-celled or more complex, could once have thrived there.

CheMin sends an X-ray beam through tiny samples of Martian soil or rock, recording how the beam scatters as it bounces against atomic planes of the different minerals contained within. The technique, called X-ray powder diffraction (XRD), has been around for a long time, but the tools commonly used were not practical for a robotic mission millions of miles from the nearest human hands.

"To do powder diffraction and get good data, you need to have roughly a million grains of the same type within the volume you're analyzing," says Philippe Sarrazin, who was the lead developer of CheMin at Ames Research Center and later founded a company that sold commercial instruments based on its technology. Technicians would grind a fine powder, with grains just 10 to 50 microns in diameter, press it into a flat cake between two pieces of plastic, reminiscent of a microscope slide, and put it in a massive XRD machine, which points an X-ray beam at it from different directions.

Absolutely no part of that process made sense for a robot on Mars: "Everything relies on very precise motions and very heavy equipment," Sarrazin says.

The biggest problem was that, to make the instrument smaller, the sample chamber also had to be smaller. But since traditional XRD still requires a million grains to get enough data points, that meant the grains needed to be even smaller as well. NASA engineers first considered making grains smaller than one micron in diameter, or less than a hundredth the width of a human hair. The task proved basically impossible, Sarrazin says: by the time you ground the material that finely, even if you could do so reliably

This self-portrait of NASA's Curiosity rover was taken at the Namib Dune on Mars, where activities included scooping up soil for analysis. One tool it uses to analyze the minerals in the soil is an X-ray Diffraction (XRD) device called CheMin, designed to be smaller, more rugged, and more automated than previous XRD machines.

on Mars, you'd ruin the crystalline structure you were attempting to analyze.

Then they stumbled onto a game-changing discovery: when you vibrate a bed of grains, they flow in a predictable, cyclical pattern. It's called granular convection, and it had been seen before, but no one had ever thought to apply it to XRD. The CheMin team quickly realized this phenomenon could solve all the problems they were encountering.

"All we had to do is shake constantly, and the powder would flow. We could shoot a small X-ray beam and material comes into it and out of it. It also turns the grains around, and by turning the grains, offers different crystalline orientation, which further enhances the quality of the data," he explains.

Because they were able to see grains from so many different orientations, they could use fewer, bigger grains, about the texture of sand. That was a huge plus, explains David Blake, CheMin principal investigator at Ames: "Bigger grains are easy to transfer from one place to another. They're also easy to make: when the drill operates on Mars, it creates samples that are about 150 microns and below." All the sample-handling instrument had to do was pour the dirt into a sieve and shake that into the CheMin sample chamber.

Sarrazin immediately began working on a design for a miniaturized XRD device using a shaker hacked from a $2.99 RadioShack buzzer. "It was nothing like the final instrument, but it made the point. If you vibrate the material, you can get good data from poorly prepared samples," Sarrazin recalls.

"That was the eureka moment. I remember going back home and telling my wife, 'This is going to Mars. It's going to make it work.'"

The key innovation of CheMin was that it didn't require samples to be finely ground into powder. In fact, the rock grains need only to be small enough to fit through this screen installed on Curiosity, through which the Mars rover funnels the samples it collects with its robotic arms.

Technology Transfer

Sarrazin worked with NASA lawyers to file for a patent covering the vibration technique in 2003, knowing it was something that could have applications in industry. Shortly afterward, he left NASA to form his own company, inXitu Inc., but his work on the instrument continued.

In 2004, Ames granted inXitu two Small Business Innovation Research (SBIR) contracts to pursue the project, which was now destined to travel to Mars on the Curiosity rover. Although the vibration concept worked, there were still a number of practicalities to figure out, including how to vibrate the sample at high intensity without vibrating everything else at the same time.

Sarrazin also needed to test whether the process would work on Mars, where gravity is around a third of Earth's gravity. The models the team was using suggested they would need to scale down the shaking proportionally. They didn't have the funding, though, to run tests to verify this on suborbital flights, which can run $750,000 each. So Sarrazin, who was earning his pilot license at the time, devised an enterprising solution.

"With my instructor, we went over the ocean and did our own microgravity flight with a small Cessna. Doesn't replace a proper microgravity test, but we didn't have that, so it was the only data point we could collect for the money we had at non-Earth gravity."

"We couldn't sustain low gravity for more than a few seconds, and our results were not very precise. But what we found more or less validated the model," Sarrazin says.

The design for CheMin was completed at the Jet Propulsion Laboratory, and the instrument incorporated into the Mars Science Lab, where it is successfully analyzing samples gathered during Curiosity's trek across Mars. "We have actually seen suites of minerals that suggest that conditions were suitable, and energy was available, to early organisms, if they existed," Blake reports. "It's really exciting."

And Sarrazin was able to use the work he did for CheMin to create a product for his new company: "I put in everything we had developed in CheMin: the same technique for collecting the sample, the same methods to for processing the data. All the things I'd put into the prototypes for NASA, I put into this first product we developed."

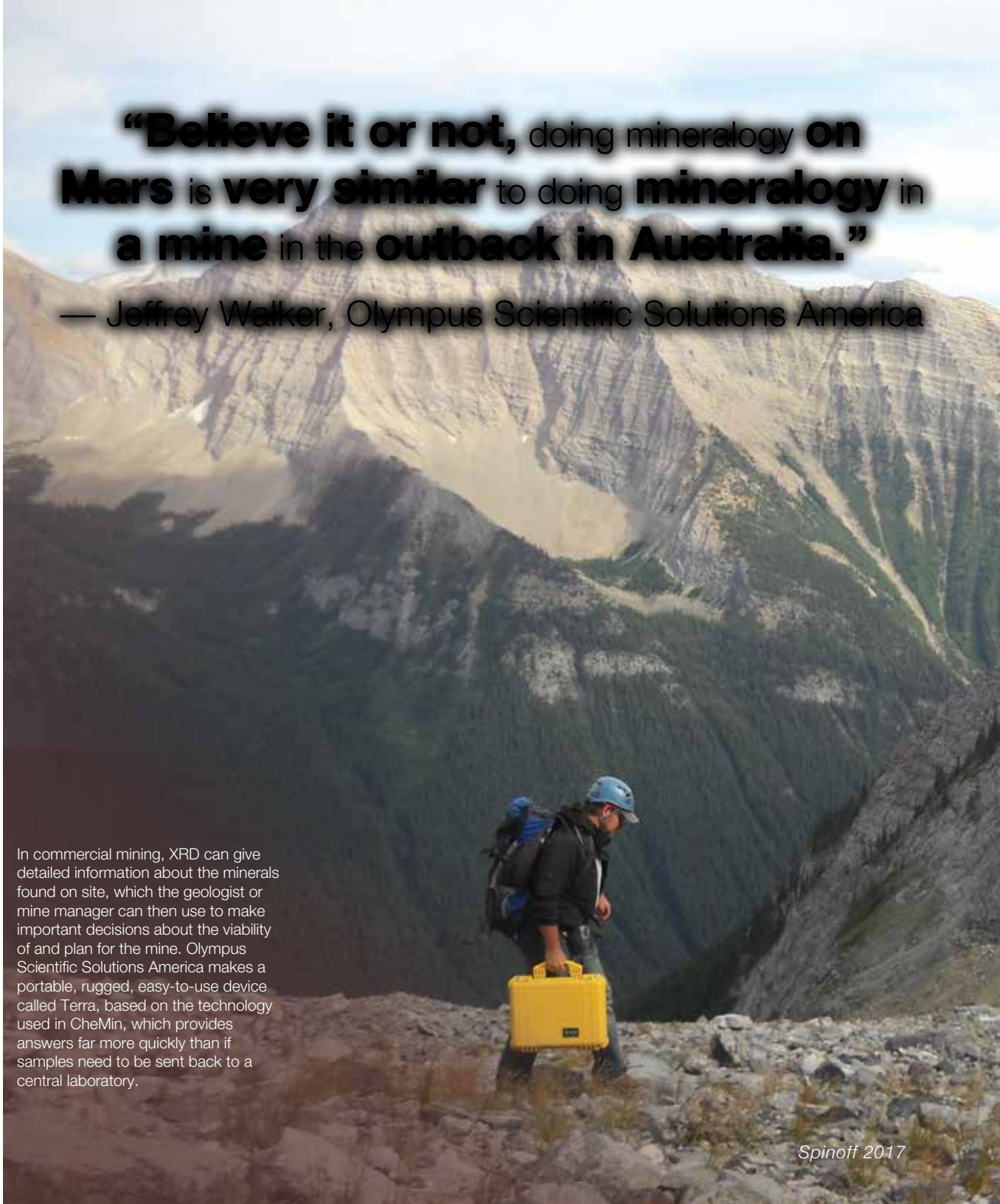
The product incorporated the work he'd done during the SBIR contracts, and it was also based on a license for the patent he filed while working for NASA.

Benefits

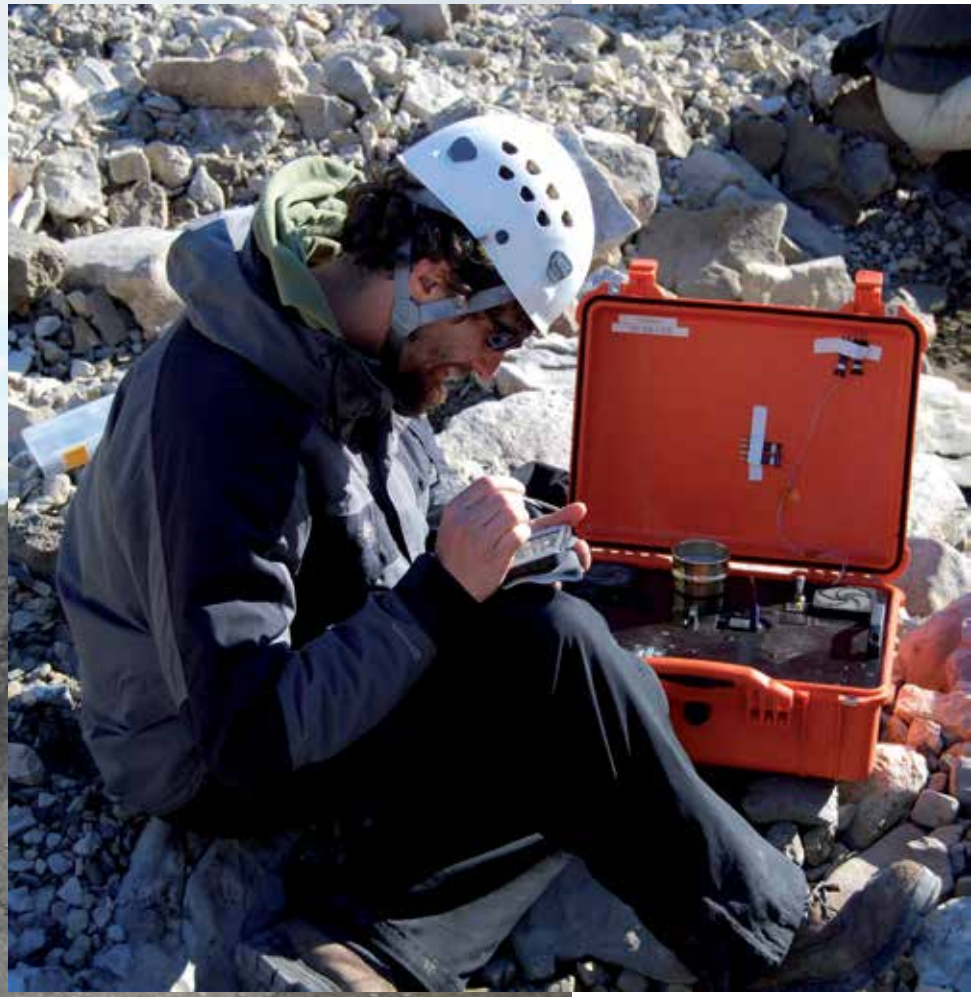
inXitu's XRD mineral analyzer was unlike anything else on the market: it was small, easy to use, and extremely rugged, and the company could sell it at a fraction of the cost of other instruments.

"There was a lot of expertise that went into using an XRD instrument," says Sarrazin of the previous laboratory-based versions, especially in preparing the sample to the correct specifications to get a good reading.

His new design "allowed a very simple sample prep method that you can do in the field, whether it's hot or cold or you're wearing gloves," he explains: take a hammer and knock out a rock fragment, and use that same hammer to crush it. Then pour it into the sample cell; the XRD analysis is "pretty much a one-button operation." The unit could be used by anyone in the field, eliminating the need for a highly-trained technician to perform the XRD analysis or the long wait for a sample to be sent to a lab for analysis.



In commercial mining, XRD can give detailed information about the minerals found on site, which the geologist or mine manager can then use to make important decisions about the viability of and plan for the mine. Olympus Scientific Solutions America makes a portable, rugged, easy-to-use device called Terra, based on the technology used in CheMin, which provides answers far more quickly than if samples need to be sent back to a central laboratory.



The easy sample preparation requirements—knock a rock fragment loose and crush it with a small hammer—plus the portability, low cost, and one-button operation have made the Olympus TERRA and BTX II Benchtop XRD devices popular in the oil and gas industry, as well as with pharmaceutical companies and drug watchdog groups.

That all makes for a very attractive product for industry, says Jeffrey Walker of Olympus Scientific Solutions America. "Believe it or not, doing mineralogy on Mars is very similar to doing mineralogy in a mine in the outback in Australia. You need something robust. You need something that can handle harsh environments," Walker says.

Olympus, based in Waltham, Massachusetts, bought inXitu in 2011 and now sells the XRD device in two models: TERRA and BTX II Benchtop. The instruments are largely identical, though the TERRA comes in a rugged case and runs on a battery pack.

"With TERRA, you can be on the side of the mountain taking rock samples, doing XRD right at the site," Walker says, and where laboratory XRD equipment can cost hundreds of thousands of dollars, the Olympus models cost less than a hundred thousand.

One of Olympus' largest markets is oil and gas exploration: by analyzing the minerals the drill is encountering, you can determine when you've hit the "pay zone" where the oil or gas is. "Particularly in shale gas, where they use directional drilling, XRD analysis is even more important, because they will take a look at the mineralogy to determine where they want to steer the drillhead," Walker explains.

Pharmaceutical companies and drug watchdog groups are also big customers. They use the XRD device, typically the BTX II Benchtop model, to test drug composition, to ensure the manufacturing is being done correctly, and to weed out counterfeits. "We're also expanding into areas of hazardous materials identification, important for global security. Quick identification of explosives and other hazardous materials is helping to enable the safety and security of the world," Walker adds.

Sarrazin credits a huge part of the success of the XRD instrument, both at NASA and in the private sector, to the SBIR contracts he got in 2004. "Both sides really benefited from the SBIR program, and none of that would have happened without that seed money." ❖

Low-Cost Flow Meters Bring Efficiency, Reliability to Nuclear Plants

NASA Technology

The technology looks unassuming enough: circular metal plates with multiple holes in them. The plates usually sport a large central hole surrounded by perhaps five or six smaller ones, although there may be anywhere from 2 to 200 openings.

But these deceptively simple devices have won awards and saved millions—possibly billions—of dollars across a gamut of industries. The simplicity, which lends itself to a low price tag and high durability, is part of the balanced flow meter's charm (*Spinoff* 2004, 2012), but this is only the start of its list of selling points.

Thanks to a relatively recent partnership, nuclear energy has become the latest industry to begin reaping the benefits that accompany these custom-engineered, perforated discs.

In the 1990s, Marshall Space Flight Center undertook research into using artificial intelligence to manage the health of propulsion systems and plant equipment, with the help of a company called Quality Monitoring and Control (QMC). Among various tools and components needed to gather system health data for artificial intelligence programs was a meter to measure the flow of liquid oxygen in the Space Shuttle's main engines.

Earlier Shuttle engines had included turbine-based liquid oxygen flow meters, but these were abandoned after one of their blades came off during testing and bounced into the propellant throttling valve, causing a fire that totaled both the engine and the test stand it was mounted on in one of the worst test accidents in NASA's history. In researching artificial intelligence applications, though, the engineers concluded that, aside from any risks they introduced, the flow meters also weren't nearly accurate enough to detect significant hardware failures.

In 2001, Marshall and QMC entered into a cooperative Space Act Agreement to split the cost of creating a better solution. There are many different types of flow-meter technology, and plates with a single hole in them had long been among these, but they have definite drawbacks.

This is a typical balanced flow meter assembly Graftel might supply for a nuclear plant, with a flow plate custom designed by A+ FlowTek and a manifold integrated by Graftel.

For example, they cause a drop in fluid pressure and often generate loud noise.

The innovation QMC devised with the help of NASA engineers and funding was to replace the single hole with a carefully calculated series of holes. The company's software determines the optimal number, size, shape, and placement of the openings, depending on factors like flow rate, pipe diameter, temperature, and the substance being metered.

"Our flow plates cause very little permanent pressure loss, if any, and the accuracy is superior to the best flow meters out there in industry," says Paul Van Buskirk, who helped invent the meters at QMC and then cofounded spinoff company A+ FlowTek to market the technology.

Technology Transfer

Marshall worked with QMC to secure an exclusive patent for the balanced flow meter.

"The NASA Technology Transfer Office realized the tremendous industrial implications of this metering technology, and they funded a test program to evaluate balanced flow meter performance in gasses and liquids," says Anthony Kelley, lead flow research engineer at Marshall and co-inventor of the balanced flow meter.

Earlier flow meters in the Shuttle's main engines had error margins of about 2.5 percent. Testing showed that QMC's meters were accurate down to 0.2 percent, even in the harshest environments.

In the years following the partnership, A+ FlowTek has successfully marketed the technology to aerospace companies, chemical plants, refineries, power plants, pharmaceutical plants, and others all over the world. It was named Marshall Space Flight Center Invention of the Year in 2007, and in 2010 it won the Federal Laboratory Consortium's National Excellence in Technology Transfer Award.

That was about the time A+ FlowTek entered into an agreement with Graftel LLC of Elk Grove Village, Illinois, whose products and services cater to nuclear power plants. This was one industry the balanced flow meter still hadn't broken into, and one that adopts change slowly and has many of its own strict rules, requirements, procedures, and quality assurances.

"The nuclear industry has about the highest standards you can have," Van Buskirk says. "Graftel is the only company in the United States that really has the talent to do this."

"We know the plants, and we know the people," adds Graftel marketing manager Dave Glover.

With an exclusive sublicense for selling the meters to nuclear plants, Graftel got to work building on the

technology and adapting it for this market, designing custom manifolds with units to measure pressure change, installing temperature sensors, and creating displays that could operate in high-radiation environments, for example.

After years of rigorous testing, verification, and certification, Graftel made its first balanced flow meter sale in 2013 and has been finding customers around the world ever since.

The company gathers requirements and specifications from its customers and passes them on to A+ FlowTek, which uses its software to generate optimal flow plate designs. Graftel then manufactures, tests, certifies, and helps install the meters.

Benefits

The major benefit of the balanced flow meter is that, unlike single-hole flow plates and some other flow meters, it causes little to no drop in pressure in the fluid or gas passing through it. This is because it also acts as a flow conditioner, minimizing friction and passing along flows that have uniform velocity and pressure profiles.

"A regular flow plate with a single hole will have maybe 10 pounds of pressure drop," Van Buskirk says. "That could mean hundreds or thousands of dollars in lost production per hour." By increasing flow efficiency, the meter pays for itself within weeks when compared to those based on a single-hole plate, he says.

"Balanced flow meters are typically considered a green technology due to the substantial reduction in fluid pump energy requirements," Kelley says. "One company unofficially stated a savings of $5 million over three years of operation using a $5,000 unit."

Other instruments commonly used in the nuclear industry, such as ultrasound flow meters, can produce inconsistent results, whereas balanced flow meters are consistently accurate.

It's also the only flow meter that can obtain accurate results even when placed near a bend in a pipe, which causes flow disturbances, another plus for nuclear plants. "In a lot of situations, the pipes in nuclear plants aren't just straight—they can be all over the place," Glover points out.

The flow plates are cheaper than many alternatives, last longer, and are virtually maintenance-free. They are also resistant to the buildup that often plagues other flow meters. "Instead of months, they'll work for 10, 15 years, probably forever," Van Buskirk says.

And while single-hole flow plates can reach volumes up to 115 decibels—about as noisy as a loud rock concert—the plates A+ FlowTek designs are barely audible.

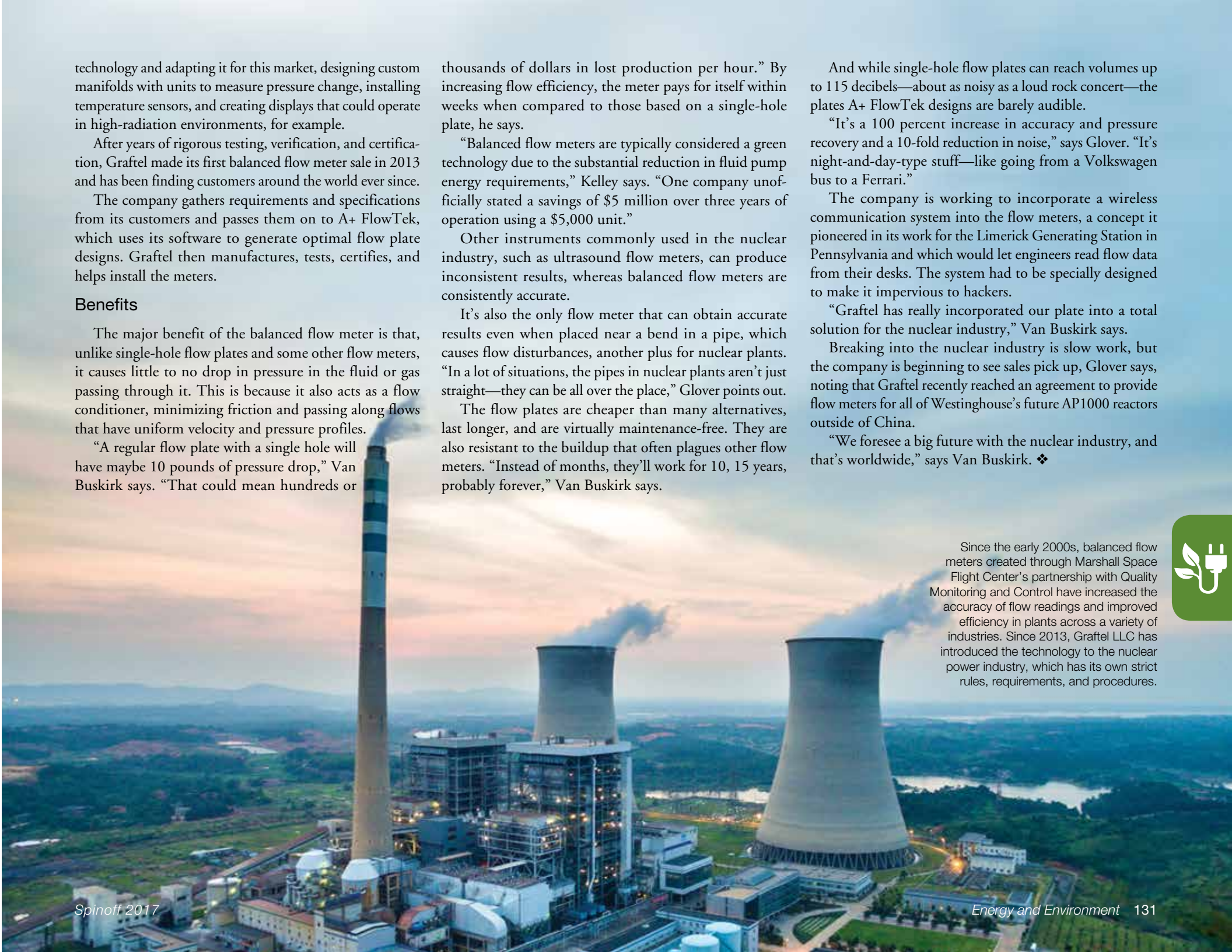
"It's a 100 percent increase in accuracy and pressure recovery and a 10-fold reduction in noise," says Glover. "It's night-and-day-type stuff—like going from a Volkswagen bus to a Ferrari."

The company is working to incorporate a wireless communication system into the flow meters, a concept it pioneered in its work for the Limerick Generating Station in Pennsylvania and which would let engineers read flow data from their desks. The system had to be specially designed to make it impervious to hackers.

"Graftel has really incorporated our plate into a total solution for the nuclear industry," Van Buskirk says.

Breaking into the nuclear industry is slow work, but the company is beginning to see sales pick up, Glover says, noting that Graftel recently reached an agreement to provide flow meters for all of Westinghouse's future AP1000 reactors outside of China.

"We foresee a big future with the nuclear industry, and that's worldwide," says Van Buskirk. ❖



Since the early 2000s, balanced flow meters created through Marshall Space Flight Center's partnership with Quality Monitoring and Control have increased the accuracy of flow readings and improved efficiency in plants across a variety of industries. Since 2013, Graftel LLC has introduced the technology to the nuclear power industry, which has its own strict rules, requirements, and procedures.

Computer Learning Program Inventories Farmers' Fields

NASA Technology

There are now countless Earth-imaging satellites circling the globe, with more being sent up each year than the previous year. Yet with all those lenses peering down at the planet, there is still no program to stitch the images together into a complete and regularly updated portrait of Earth.

This was what GeoVisual Analytics, a relatively young company based in Boulder, Colorado, proposed: an automatically updated, global land classification map based on imagery from the Landsat mission, which captures an image of the entire planet every 16 days.

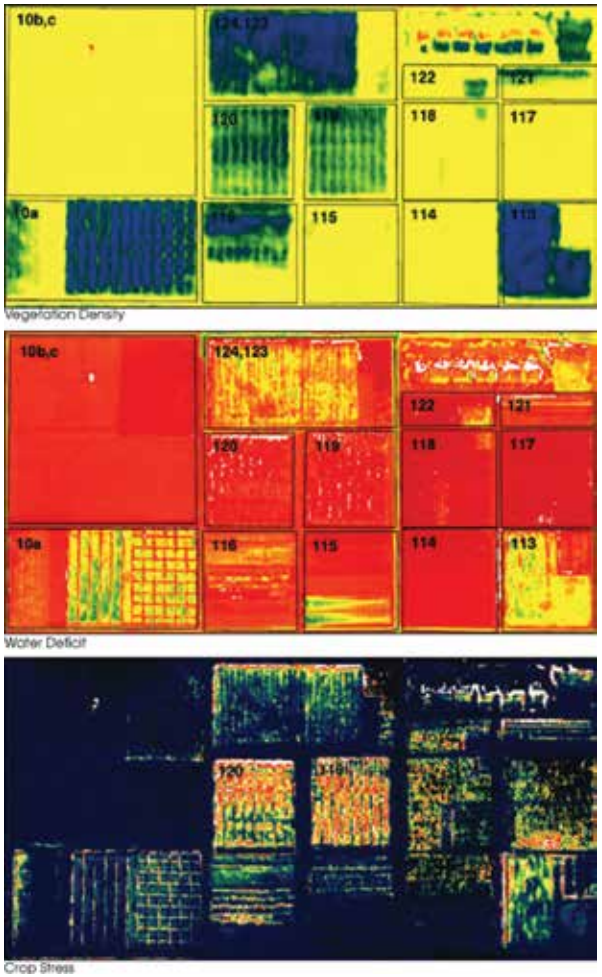
With funding from a 2014 Small Business Innovation Research (SBIR) contract with NASA's Goddard Space Flight Center, the company set out to fuse satellite imagery with existing geographical datasets, work out land classification techniques, and enable continuous updating.

By coupling the imagery with "ground truth" data from a platform GeoVisual developed under two other SBIR contracts with NASA's Stennis Space Center, the system would continually improve its accuracy and ability to classify ground cover. The OnSight platform developed at Stennis basically crowdsources information about conditions on the ground, letting users report details and correct inaccuracies. This would also add new layers of information to the product.

At least that was the plan. "We hoped to use this map in a number of ways," says Dan Duffy, high-performance computing lead at the NASA Center for Climate Simulation at Goddard, who worked with GeoVisual on the project.

"One thing we would use it for would be a much higher-resolution map to put into our climate models," he says, noting that existing models have resolution of a kilometer, while Landsat has 30-meter resolution. Climate and weather are tied to land cover, he notes. "These things are important and will get to be more important as the resolution of our weather models gets down to more human scales."

Observing change over time is also important, and current images of the entire globe are updated only every four or five years, leading to inaccurate pictures and incomplete records of global polar ice melt, urban sprawl, and deforestation, Duffy says.



A wealth of information can be gathered about vegetation using hyperspectral imaging, such as vegetation density, top; water deficit, middle; and crop stress, bottom. Using algorithms and techniques it developed with funding from Goddard Space Flight Center, GeoVisual Analytics uses images of farmers' fields to let them learn more about their crops, including predicted yields.

Continually updated Earth imagery can also be used for crop prediction and precision agriculture, which GeoVisual knew from the start would be its most viable commercial application. Knowing global coverage and health of a given crop would allow prediction of the year's yield. "If you know it's going to be low or high, you can make a lot of money," Duffy points out.

One limitation the work ran up against, though, was that although Earth may be tiny on a cosmic scale, it is still positively huge to a computer server and the humans that operate it. "Ultimately it's a fairly big data problem, especially with all the images from Landsat 7, 8, and soon to be 9," Duffy says. Even NASA and the U.S. Geological Survey's massive Land Processes Distributed Active Archive Center, which hosts all the Landsat data and NASA's global Moderate Resolution Imaging Spectroradiometer data, isn't particularly equipped to mine all that information. For example, Duffy says, "They don't necessarily have the robust tools to create a global vegetation index."

And even with datasets pushing the boundaries of manageability, GeoVisual found the resolution wasn't high enough for the agricultural applications it was hoping to capitalize on.

Technology Transfer

"During their Phase I contract, they focused on using the Landsat data to better their classification scheme," Duffy says, explaining that this meant developing an algorithm that could analyze imagery pixel by pixel, assigning a vegetation index number and one of 30 or 40 land-cover classifications to each dot.

That was as far as the work got, but it was enough for GeoVisual to develop what it calls its Computer Learning Imagery Platform (CLIP).

"The work for Goddard was basically land classification from satellite imagery—training algorithms to classify land types using multispectral imagery," says Jeffrey Orrey,

The Computer Learning Imagery Platform (CLIP) that GeoVisual Analytics developed with NASA funding was designed to map global land cover classifications using satellite imagery. To chart farmers' fields, the company uses CLIP to analyze higher-resolution drone imagery.

> "The Goddard work really was the basis for what we're doing now for crop detection using aircraft and drone imagery."
>
> — Jeffrey Orrey, GeoVisual Analytics

GeoVisual's cofounder and CEO, noting that this could be satellite or aircraft imagery. In the end, the product the company commercialized uses the higher-resolution imagery that can be achieved by aircraft imagers.

"The methodology for processing the imagery is the same, it's just a question of pixel size," Orrey says. "The Goddard work really was the basis for what we're doing now for crop detection using aircraft and drone imagery."

The company took the technology to the 2015 THRIVE Accelerator in Salinas, California, an event aimed at boosting promising startup companies in the food and agricultural technology industries, and was named as a finalist. As part of the accelerator, the company received mentoring from Taylor Farms, the world's largest producer of fresh-cut vegetables and now CLIP's first customer.

Benefits

By fall of 2015, GeoVisual was working on a contract basis for Taylor Farms, using CLIP to analyze drone imagery of fields and take inventory of crops.

Using digital images, the software can determine a crop's stages of growth and its health, allowing Taylor Farms, which partners with growers throughout the Salinas Valley, to predict yields throughout the season.

Health can be determined by the amount of infrared energy reflected relative to reflected visible light, Orrey says, explaining that healthy crops reflect more infrared light to keep cool.

He says parts of the company's OnSight platform are also integral to the work and could become more so, for incorporating observations from the ground as well as managing data. "We anticipate that aspects of OnSight would be relevant for data management of this CLIP system."

2015 was a big year for GeoVisual, which also was the judges' top pick at the Western Growers Association's *Shark Tank*-style Innovation Arena Workshop that November and took second place in the "pitchfest" at the RoboUniverse Conference and Expo the following month.

Moving forward, the company plans to expand its technology's capabilities and applications, as well as the territory it covers. Further combining CLIP and OnSight could lead to forest monitoring, for example. Conservation International is already using OnSight to monitor fires in the rainforests of Peru and Madagascar (see page122). "Agriculture and forestry are not unrelated," Orrey says. "Food security, forestry, and forest health are all very connected."

For now, though, he says, "We're very focused on agriculture, and our goal is to become the leading computer vision platform for agriculture." Eventually, the company wants to move toward the global crop mapping that was part of the initial goal of its Goddard work and would enable prediction of the world's staple crops.

"As we grow, we anticipate using these technologies on a global scale," Orrey says. "Especially when we go international, which we plan to do." ❖

Information Technology

When NASA wants to model the dynamics of atmospheric reentry, capture data from the launch pad, or undertake any number of ambitious data-driven projects, it develops cutting-edge software and information technology to get the job done. These innovations are often valuable in other applications ranging from archaeology and consumer product design to oil drilling and commercial space missions.

Laser Imaging Helps Archaeologists Dig Up History

NASA Technology

Some 10,500 years ago, what is now western Oklahoma teemed in late summer and early fall with bison, traipsing through the grassy landscape. For the humans who lived then, the huge mammals were a tempting food source, and every year a gathering near the Beaver River was timed so they could hunt the animals as they passed through.

The hunters funneled the herds into narrow, dead-end arroyos—steep gullies cut into the hillside by the river—with others waiting along the rim with spears, killing the bison by the dozens. Then they would slice off the choicest meat to eat during the gathering, leaving behind skeletons.

Walk through western Oklahoma today and there is little visible evidence of these hunting expeditions. Few bison remain, and dirt and rocks have filled in many of those arroyos.

But another look with some high-tech equipment can give archaeologists hints of the treasure troves of fossils and bones hidden below the surface. Laser-based remote sensing equipment called lidar can scan the landscape and pick up details hard to see with the naked eye. And the technology owes a lot of its development to scientists looking at something very different: planets, moons, and asteroids.

In lidar scanning, one or more lasers sends out short pulses, which bounce back when they hit an obstacle, whether clouds, leaves, or rocks. "When the pulse leaves the instrument, there is a detector that starts an electronic clock," explains scientist George Shaw, who is the laser systems lead for the Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) mission, which aims to send a spacecraft to an asteroid to collect samples and bring them back to Earth.

"When the laser pulse hits the surface and is reflected back—it's scattered, but some amount of light is reflected back—it is directed into a photo detector and that stops the clock," he explains. The instrument calculates how long it all took and, using that information, can calculate the distance from the lidar instrument to the surface the pulse just hit.

"You do that many, many hundreds of thousands or millions of times over the whole surface of the asteroid, and eventually you can build up a high resolution, three-dimensional topographic map," says Shaw, who is based at Goddard Space Flight Center.

The OSIRIS-REx Laser Altimeter (OLA) was designed with two lasers to scan the surface of the target asteroid, Bennu, and the 3D map it creates will help the mission team select a site to gather samples. "Ideally they're going to find a nice flat area," Shaw says, one without any large boulders, and which has small grains or gravel for the instruments to scoop up.

Technology Transfer

NASA has been incorporating lidar devices into missions dating as far back as Apollo 15 in 1971, and its work has helped drive forward the technology both through in-house development and through contracts with commercial companies.

Through an agreement with the Canadian Space Agency, OLA was built by Canadian firm MacDonald, Dettwiler and Associates, in partnership with Vaughan, Ontario-based Teledyne Optech, which designed the lidar.

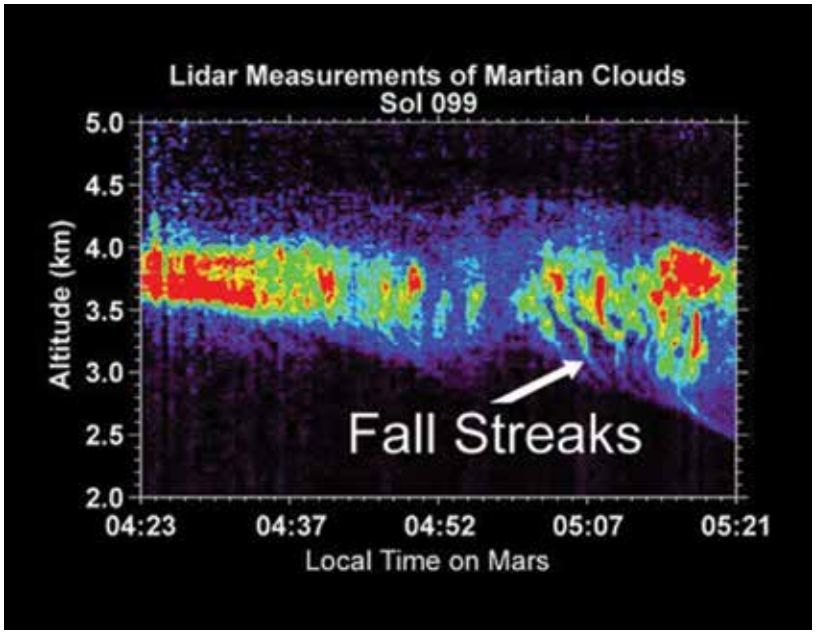
It is not the first contribution from Teledyne Optech to a NASA mission. The 40-year-old company, which also has offices in Mississippi and New York, specializes in designing and building lidar instruments, and in 2008, the instrument it provided to the Phoenix Mars lander made a huge discovery.

The ground-based lidar took measurements of the Martian atmosphere to make a profile based on the airborne dust and clouds the laser bounced against.

"What we saw in the lidar results were these streaks of brightness in the atmosphere above the lander, and the only thing it could have been was ice crystals," says Paul LaRocque, vice president of special projects at Teledyne Optech.

In other words: the Teledyne Optech lidar found snow in the atmosphere of Mars.

Since then, the company has made good use of the work it did to build the Phoenix lidar, incorporating those innovations both in OLA, which uses an updated version of the high-energy scanning laser, and in its wider commercial



The Phoenix Mars Lander (opposite) used a lidar device built by Teledyne Optech to scan the Martian atmosphere in 2008. In this graph of the lidar results, the vertical streaks on the right show ice crystals falling. Based on the temperatures recorded, the ice could only have been water-based—in other words, snow.

offerings, which benefit from the changes needed to make the instruments space-ready.

"Size, weight, and power are always the issues," explains senior engineer Jeff Tripp. "Most lidars, if we're talking about working on Earth, they're going to be hundreds of pounds and fill rooms." That wouldn't work for the Phoenix lander, of course, which had to be light enough for a launch.

"This particular unit was under 20 pounds and took up very little space—it was the size of a bread box. So getting it compact and running at a reasonable power was one of the real tricks," he recalls, one which paid off big-time for Teledyne Optech's commercial clients, who also appreciate smaller, less power-intensive instruments.

"The things we've learned on space programs, to build more compact lidars, that's helped us immensely in miniaturizing our commercial lidars," LaRocque emphasizes.

And it was one of those commercial lidars that helped archaeologists at Beaver River scan the landscape for bison kill sites.

Benefits

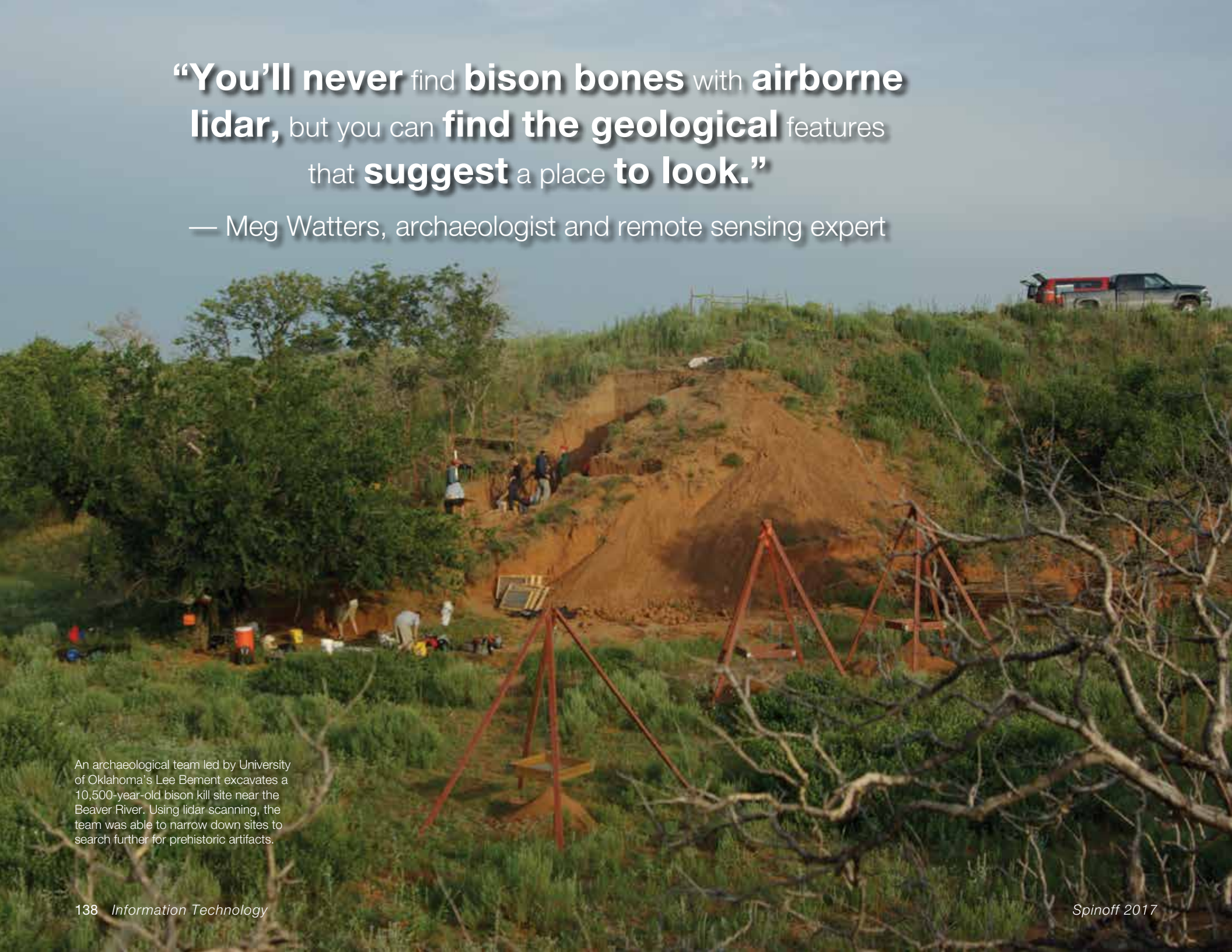
In the Beaver River area, the archaeological research team flew overhead scanning with an Optech ALTM-3100C airborne laser mapping system, operated by West Virginia University National Resource Analysis Center.

"You'll never find bison bones with airborne lidar, but you can find the geological features that suggest a place to look," explains Meg Watters, who specializes in using remote sensing and 3D imaging for archaeology, and visited the Beaver River team as the remote sensing and visualization director and presenter for television show "Time Team America."

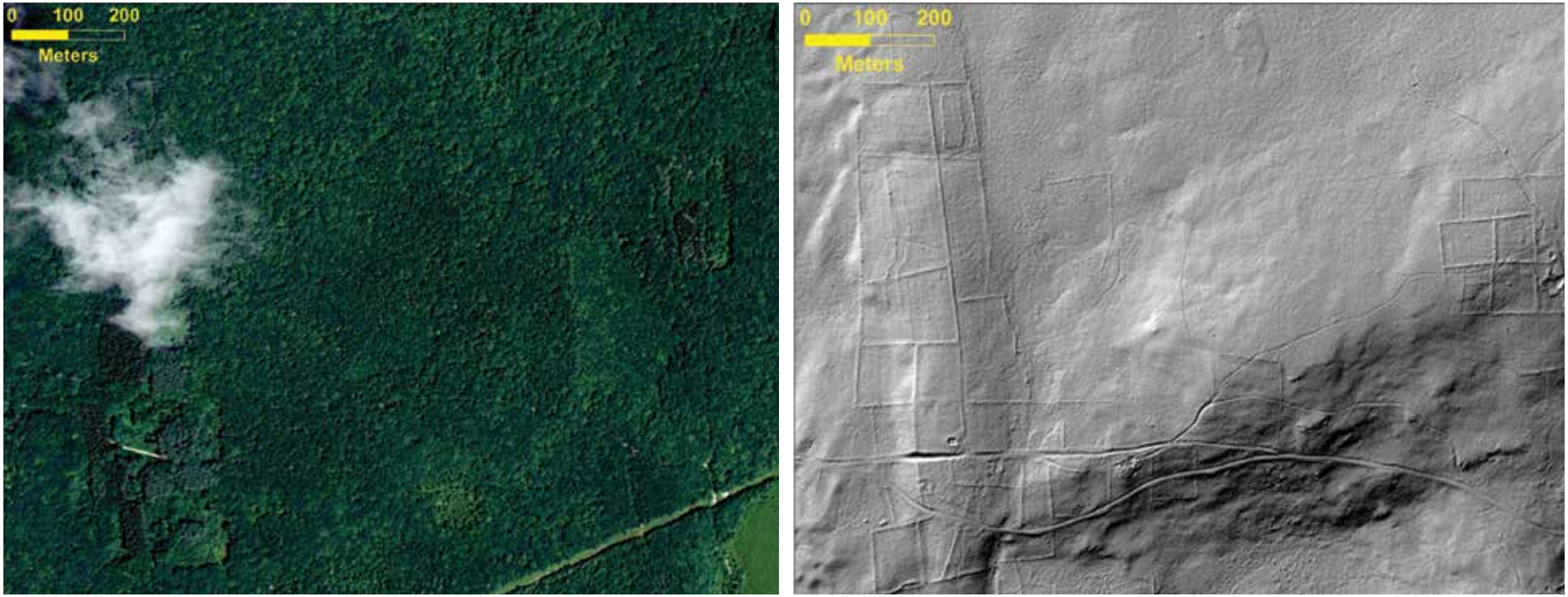
The Teledyne Optech lidar has the ability to give a 3D model of the surface that includes the grass, bushes, and trees, but also a bare-earth version, stripping all that away. That's because Optech lidars don't just bounce back once; the instruments can get up to eight returns from each laser pulse, explains LaRocque. For instance, one pulse might hit at the treetops, then in the branches, and then on the ground below.

“You’ll never find **bison bones** with **airborne lidar,** but you can **find the geological** features that **suggest** a place **to look.”**

— Meg Watters, archaeologist and remote sensing expert



An archaeological team led by University of Oklahoma’s Lee Bement excavates a 10,500-year-old bison kill site near the Beaver River. Using lidar scanning, the team was able to narrow down sites to search further for prehistoric artifacts.



On the left is an aerial photograph of a forest in Connecticut. On the right, a bare-earth lidar image gives a view beneath the overgrown vegetation, where there are remnants of stone walls, building foundations, abandoned roads, and what was once cleared farm land.

"By processing it with our software," he says, "you can then get to the bare earth and see structures or features that were so overgrown that they wouldn't be obvious at all to someone on the ground."

Watters and fellow archaeologist Lee Bement, who has led the research in the area for years, were able to pinpoint little contrasting lines in the scans that indicated a possible filled-in arroyo. They checked them out on the ground and saw more details that suggested they were on the right track, Bement explains.

Once they had promising locations, they could go in with tools to dig beneath the surface to look for the bones and other artifacts that reveal information about the people and animals who lived, hunted, and died there thousands of years ago.

The guidance from the lidar scans led them to look on the hill between two arroyos, Bement says, where "we found a processing area, where they had brought parts of a couple bison and butchered them," Bement says.

The lidar imaging has "been useful in delineating where we need to concentrate our efforts," he adds. "It saved us a lot of time and effort."

Data from lidar scans have helped lead to several other highly touted discoveries in recent years, including pinpointing the site of the legendary lost Ciudad Blanca in Honduras. That team turned to the Houston-based National Center for Airborne Laser Mapping, which uses Optech's Titan and Gemini lidars.

Although archaeologists are not the biggest market for lidar instruments, simply because the researchers often don't have enough funding for the costly devices and flights, they are increasingly turning to the technology wherever possible to gain insights for their research.

In New England, Katharine Johnson, a PhD candidate at the University of Connecticut, and advisor William Ouimet were able to advance the study of landscape history in the region thanks to several publicly available datasets from federally funded scans of Connecticut. Johnson was able to strip away the forest canopy and recognize remnants of stone walls, building foundations, abandoned roads, and what was once cleared farm land.

"Without this data, you might have to go out and measure everything by hand, which would be really difficult" across such a large region, Johnson explains.

"The advent of lidar has basically revolutionized the way we are able to study the landscape." ❖

Program Predicts Aerothermodynamics of Reentry, Subsonic Flight

NASA Technology

Traveling nearly five miles per second, the Space Shuttle began each reentry with nothing to slow it down but the air. The gasses rushing over its wings' leading edges formed a shockwave that heated the air to the point of breaking apart molecular bonds, producing an electrically charged plasma that scorched surfaces with temperatures in the thousands of degrees. For several minutes, the Shuttle would glow like the surface of the sun, after which a series of maneuvers slowed the craft to the point that it could glide safely into its relatively pedestrian landing.

Anyone designing a craft to withstand the forces and temperatures of atmospheric entry has to take into account a multitude of tradeoffs. Larger wings, for example, add weight but also generate more lift. Quicker deceleration achieved by a larger wing would also mean less heat, which would allow for a thinner heat shield.

Under the Second Generation Reusable Launch Vehicle program in the early 2000s, NASA was using various software to analyze spacecraft designs it and its contractors came up with. One problem was that computational fluid dynamics (CFD) software, while capable of producing high-fidelity aerodynamic and aerothermodynamic performance predictions, takes a long time. Modeling the temperatures and aerodynamics throughout the descent of a single vehicle with a CFD program "can take thousands of hours on hundreds of computers," says David Kinney, an engineer with the Systems Analysis Office at Ames Research Center.

There were faster, simpler codes, but none that could predict both aerodynamics and heating, and each of those required a different, hand-mapped simplification of the original computer-aided design (CAD) model. "Going from the CAD geometry to engineering-level tools, there was a lot of manual work to get it into the right formats for different codes," Kinney says. "We wanted to be able to take the geometry as the designer envisioned it and do aerodynamic and aerothermodynamic analysis all at once."

To fill that need, he and his team created what's now known as the Configuration-Based Aerodynamics (CBAERO) program. The software defines the shape of a vehicle within an unstructured mesh of triangles, taking advantage of existing routines for translating designs from CAD. No simplification is necessary. The resulting surface grid also translates easily to higher-fidelity CFD software.

The code was used to create an aerothermal database to guide the design of the Orion spacecraft's heat shield. The database predicts forces and temperatures across the vehicle's surface at a range of speeds, dynamic pressures, and angles of trajectory.

Once a trajectory is settled on, "the point where there's the highest heating will define what kind of thermal protection system you're going to use," Kinney says. Duration of heating will determine how thick the heat shield needs to be.

CBAERO can also produce results in "batch mode," automatically running results for a family of vehicles with a range of design parameters. "Folks here at NASA might run thousands of cases for parametrically different vehicles," Kinney says. "You wouldn't want to set each of those up by hand."

A handful of high-fidelity CFD analyses can be imported into the program and used to anchor thousands of data points within an aerothermal database or a batch of atmospheric entry models, ensuring reliable results.

The software also has a module for aerodynamic analysis at subsonic speeds, which more recently was adapted to assist in the design of lighter-than-air vehicles, he says. "There are some specific methods we added to the lower-speed module of code to support analysis for dirigibles and the like."

And the program includes models for the atmospheres of all the planets in the solar system except Mercury, whose atmosphere is negligible, enabling engineers to predict descents for any planetary lander.

Technology Transfer

CBAERO has come to be used by engineers across all of NASA's field centers. Made available through software usage agreements in 2006, the program has also been used by more than 20 businesses, including just about every company building commercial space vehicles, as well as at least half a dozen Department of Defense agencies and four universities.

And it's not just used for designing spacecraft. For example, one branch of the U.S. Air Force uses it for fighter jets, large transports, and unmanned aerial vehicles while another uses CBAERO to assess potential threats from foreign missiles and hypersonic glide vehicles.

The program is available at no cost through U.S. academic and Government-purpose releases, meaning it's offered to academic institutions, Federal agencies, and their contractors.

It was one of two programs named NASA Software of the Year for 2014.

Benefits

"CBAERO is our work horse when we have to do rapid assessment of different configurations," says Luis Bermúdez,

The Russian Soyuz spacecraft streaks across the night sky, generating an electrically charged, white-hot plasma trail. Traveling at hypersonic speeds, spacecraft returning to Earth experience extreme stresses, including temperatures in the thousands of degrees, as they decelerate through the planet's atmosphere.

lead aerosciences engineer at Orbital ATK's Space Systems Group.

He first encountered the software in 2006 when he was lead aerodynamics engineer for the Dulles, Virginia-based company's work on Orion. Since then, he says, he has used the program on all his atmospheric entry projects. These have included an inflatable aerodynamic decelerator for the Defense Advanced Research Projects Agency's now-defunct Rapid Eye project, which would have sent an unmanned aerial vehicle anywhere in the world within two hours via intercontinental ballistic missile, and entry systems for the commercial Cygnus spacecraft now used in resupply missions to the International Space Station. And he used it for preliminary designs for the Prometheus spacecraft Orbital proposed under NASA's Commercial Crew Development program.

"CBAERO is one of those tools we use very often," Bermúdez says. "The beauty is that it runs very, very fast, and it produces results within minutes." Often, he says, after running a case, he wants to tweak a small piece of the design to optimize it. "You can do that because it runs within seconds or minutes. If you had to wait a week, it wouldn't be feasible."

As Kinney puts it, "You're talking a few seconds, versus thousands of hours, on a single test case."

While CBAERO is mainly used for preliminary design work before CFD modeling takes over to produce higher-fidelity predictions for mature designs, Bermúdez says, the fact that the program defines geometries the same way as CFD software also saves the work of recreating a model in a different format.

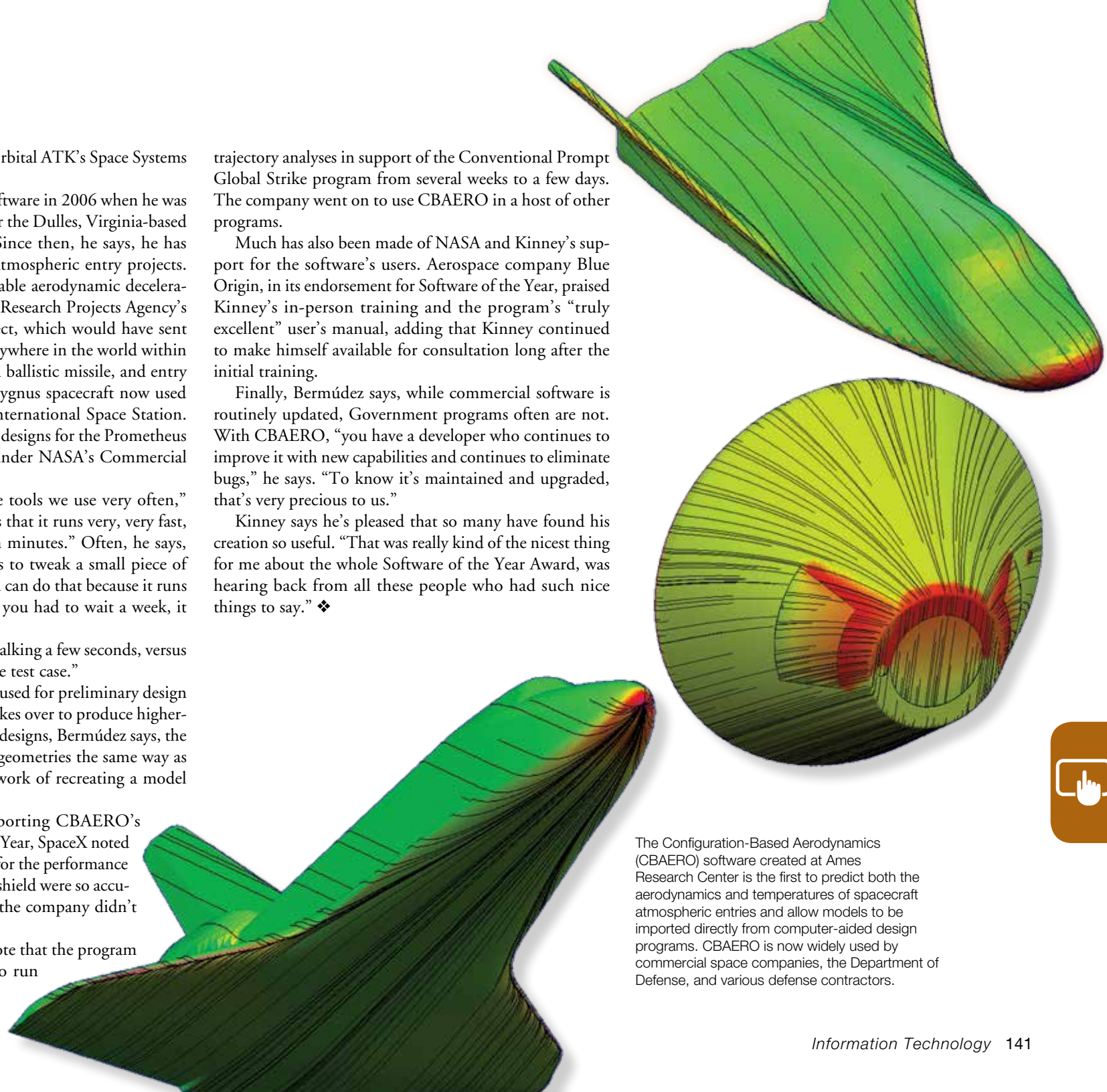
That said, in a letter supporting CBAERO's nomination for Software of the Year, SpaceX noted that the program's predictions for the performance of its Dragon spacecraft's heat shield were so accurate that, after CFD analysis, the company didn't change a thing.

Aerospace Corporation wrote that the program reduced the time necessary to run trajectory analyses in support of the Conventional Prompt Global Strike program from several weeks to a few days. The company went on to use CBAERO in a host of other programs.

Much has also been made of NASA and Kinney's support for the software's users. Aerospace company Blue Origin, in its endorsement for Software of the Year, praised Kinney's in-person training and the program's "truly excellent" user's manual, adding that Kinney continued to make himself available for consultation long after the initial training.

Finally, Bermúdez says, while commercial software is routinely updated, Government programs often are not. With CBAERO, "you have a developer who continues to improve it with new capabilities and continues to eliminate bugs," he says. "To know it's maintained and upgraded, that's very precious to us."

Kinney says he's pleased that so many have found his creation so useful. "That was really kind of the nicest thing for me about the whole Software of the Year Award, was hearing back from all these people who had such nice things to say." ❖



The Configuration-Based Aerodynamics (CBAERO) software created at Ames Research Center is the first to predict both the aerodynamics and temperatures of spacecraft atmospheric entries and allow models to be imported directly from computer-aided design programs. CBAERO is now widely used by commercial space companies, the Department of Defense, and various defense contractors.

Data Acquisition System Captures Machine Performance

NASA Technology

When you launch rockets, even the smallest deviation from design can create big problems—and they're hard to fix for next time unless you know exactly what happened. The same is true for any venture where even a small malfunction can translate into major lost revenue.

That's where data acquisition systems come in. Designed to capture and store information about the performance of and environment around a machine, they give engineers the information they need to see what happens when the machine works as designed—and when it doesn't.

For NASA, that information is especially crucial when designing something new, like the Space Launch System (SLS), the vehicle planned to propel the first humans to Mars one day.

For instance, "on launch day, they use the data to determine when our real T-0 was. When you release all the load from the launch platform, that's a pretty good idea of when the actual launch took place," explains NASA's Jeffrey Crisafulli, who manages the Launch Equipment Test Facility at the Kennedy Space Center. Thanks to sensors embedded in the launch platform, sending 200,000 samples per second, engineers can calculate that launch moment to the exact millisecond, he explains.

"Our launch control system tries to make it happen at a certain time, but you need to measure when it actually occurred," he says. If there are any delays or differences, the engineers need to know. For one thing, there are many connecting arms, called umbilicals, in the launch platform, delivering fuel and performing other important last-minute functions, which disconnect moments before liftoff. "You don't want any umbilicals touching the rocket again once it's fired."

In all, there are more than 500 sensors installed in the SLS mobile launch platform, measuring everything from temperature to strain, pressure, load, and acceleration. Sensors are installed on the umbilicals, along the 350-plus-foot tower, and in the base.

NASA needed a system that could monitor the signals from all these sensors, store the data, and simultaneously send it to the launch control center miles away. To do that, its engineer's turned to Dewetron.

Technology Transfer

Dewetron, of Wakefield, Rhode Island, specializes in building data acquisition systems that can be used for machines in any industry, whether they're spacecraft launch platforms or paper mills.

"We're providing the instrument that the engineers who design and build these machines rely on to capture data," explains Dewetron President Grant Smith. "Our instruments measure strain, pressure, acceleration—basically, if you can sense it with your body, with your senses, then typically we need to measure it. And we do."

Dewetron has stock products it offers, but for the SLS launch platform, it had to build something more powerful. Unlike many systems that have separate signal conditioners to receive and process signals for different types of sensors, NASA wanted a single, universal signal conditioner for all the sensors. That would mean fewer parts to maintain and replace, keeping the cost down, and also make it easier to analyze the data later, explains Smith.

The sensors and signal conditioners convert the physical phenomena into a voltage, which then registers as a wave form on a graph—imagine an old-fashioned lie detector with a bunch of little pens drawing continuous lines on a piece of paper, now digitized. In order to compare the signals from the whole range of sensors, those waves need to have the same phase characteristics. That way, you can lay the different results on top of one another, without any time delay from one signal to the next.

Dewetron was able to take one of their existing signal conditioners, designed for a strain gauge, and increase its voltage input range, as well as add additional capabilities

The mobile launch platform for the Space Launch System (SLS) travels to the launch site at NASA's Kennedy Space Center in Florida. One of the important roles of the Dewetron data acquisition system installed throughout the structure is to capture information on important details like whether the platform base is stable and balanced before launch.

> “It’s all built on the solid foundation of what NASA challenged us to do with the original data acquisition program for the mobile launch platform.”
>
> — Grant Smith, Dewetron

so it would be able to read the signals from all the different types of sensors on the mobile launch platform. It also increased the voltage isolation to minimize any chance of interference between sensors, which, “from an engineering point of view, was very challenging,” says Smith.

The signal from a strain gauge is measured in millivolts. NASA needed the conditioner to be sensitive enough to register those tiny signals, while also able to withstand a 300-volt surge, some 300,000 times bigger. At the same time, NASA wanted it to have a high bandwidth, able to reproduce a signal hundreds of thousands of times a second.

“It’s hard to have all three,” Smith explains. “Usually if you have a lot of isolation, that lowers the bandwidth, and vice versa. It’s a tough balancing act, and it took a lot of engineering to make it all happen.”

Dewetron also used a distributed design that wired all the sensors to just a few nodes in different locations on the mobile launch platform. These nodes used inexpensive Ethernet cables to connect back to the launch control center, dramatically reducing the amount of costly and heavy instrumentation cable.

Benefits

One of the best features of the Dewetron system, Crisafulli says, is that it is very easy to use. “You buy it, you follow their operations manual, and anybody can make this work. You don’t have to be a rocket scientist to take information with a Dewetron system.”

But even more importantly, it was able to handle the tough demands of the NASA contract. “Other companies make universal signal conditioning amplifiers, but they take up a lot of space and cost a lot of money. And they’re not as robust as Dewetron’s system,” explains Crisafulli. Plus, these other systems are “probably not able to survive a launch event, which has lot of high vibrations. It’s a rough place.”

Sensors measuring anything from strain to temperature, pressure, load, or acceleration plug into the Dewetron system, which records how each performs so engineers can analyze the data later. Many systems have separate systems for different kinds of sensors, but at NASA’s request, Dewetron built a machine that could read every kind of sensor.

This accomplishment, ultimately, was what made the DAQP-STG signal conditioner into an attractive spinoff for customers beyond NASA. “For most of our customers that do anything related to strain gauges, it’s the ideal conditioner. It can handle nearly every kind of resistive sensor, it provides higher isolation than we ever did before, and it has a very high bandwidth. It’s a triple threat,” Smith says.

The company has taken this technology and driven it into subsequent models, too, including the HSI-STG, a signal conditioner with the same basic specifications as NASA’s DAQP-STG, except with a bandwidth of two megahertz, and the TRION-2402-MULTI module, which adds a separate 24-bit analog-to-digital converter on each channel.

United Launch Alliance has adopted the TRION-2402-MULTI modules for its Atlas and Delta launch facilities at both Cape Canaveral and Vandenburg Air Force Base, and has already launched several successful missions with this new hardware.

“It’s all built on the solid foundation of what NASA challenged us to do with the original data acquisition program for the mobile launch platform,” says Smith.

Dewetron’s customers include every major car company, from Ford to BMW to Nissan, he says, and not only do the companies use the Dewetron instruments to test their own cars, they use it in market research to test their competitors’ cars. Dewetron systems are also used by car parts makers, including Visteon, Bridgestone/Firestone and Siemens.

And the market extends well beyond automobiles, with customers in every industry, including companies that specialize in structural monitoring, ones that do machine testing, and a wide range of commercial aerospace companies, including Boeing, Lockheed Martin, and Bell Aerospace. “We’ve sold many thousands of these conditioners,” Grant says, sometimes in orders of 800 or more, which, at roughly a thousand dollars each, is great for the company’s bottom line.

NASA’s high standards are great for industry, he emphasized. “They have these requirements which are extraordinary, because of the nature of the work, and that pushes everybody forward to meet them. And then we, almost by accident, invent things that have other, unanticipated applications here on Earth.” ❖

Light-Analysis Software Explodes across Industries

NASA Technology

Edward Freniere and a partner founded Lambda Research Corporation in 1992 with the idea of developing software to simulate the behavior of light, basing their first product on public-domain stray light analysis software created by Honeywell. "We had an educated hunch there were other applications for this kind of software," he says.

Little did they realize just how many other uses such a program might find.

Indeed, predicting and eliminating stray light was what NASA's Jet Propulsion Laboratory (JPL) had in mind when it granted the Littleton, Massachusetts-based company a Small Business Innovation Research (SBIR) contract the following year to develop a new, more user-friendly program.

The Agency needed an efficient way to see how light from objects outside its imagers' field of view would affect the pictures they produced, because this stray light can overpower dimmer objects that might be the camera's true target.

That was the beginning of TracePro (*Spinoff* 1997), which remains Lambda's flagship product. By then, Freniere says, the two business owners figured the software would also have applications in the automotive and commercial lighting industries. "I had no idea it would be useful, for example, for displays or even some non-optical applications."

> "Anywhere you're trying to see what light is doing, we've added those functions to TracePro."
>
> — Michael Gauvin, Lambda Research Corporation

But it was and still is, just as it also is useful in the defense, medical, consumer electronics, solar energy, and light pipe industries.

Tolis Deslis, who has since left NASA, was an optical engineer at JPL when Phase I and II SBIR contracts were granted to Lambda to develop the software. At the time, he was designing the lenses for the Earth-observing Terra satellite's Multi-Angle Imaging Spectroradiometer (MISR), which became the first imager devised with the help of TracePro.

"Say the sun is outside the field of view, and some of its light is getting into the system," he says. "I need to know, given this amount of light, how much is going to make it into the detector." Imagers can then be altered to ensure accuracy. However, this is no simple task. Each ray that hits a surface in the imager reflects as perhaps a hundred rays, each of which can split into a hundred more upon their next reflection, with the rays collectively losing power with each bounce, Deslis says. "I cannot map that by hand. There's no way."

There was a program available for modeling ray behavior, but it was expensive, difficult to use, and incompatible with both Windows and the existing computer-aided design (CAD) software used to design the instruments, he says. The user had to recreate the entire geometry of the instrument that was to be analyzed, instead of just importing it from a CAD program.

One of the many medical uses for TracePro is validating designs for blood oximeter pulse monitors. The monitors measure oxygen in the blood by observing how light travels through the fingertip.

Using the first software package Lambda delivered to NASA, Deslis and his colleagues were able to easily analyze designs for the Terra MISR and found that the aluminum lens housing initially planned would admit too much stray light into the system. They opted instead to coat the inside of the lens housing with a compound that would absorb incoming light.

"We found this was going to be acceptable in terms of what scientists wanted in signal-to-noise ratio," Deslis says, adding that the software successfully predicted how light would behave in the imager. The ability to accurately recreate the reflective properties of different surfaces, materials, and textures was as important as being able to predict how much stray light would enter a system and where, he says.

Terra, launched in 1999, is still circling the globe and remains the flagship of NASA's Earth Observing System. Numerous other NASA imagers have since been designed with the help of TracePro.

Technology Transfer

Before the end of the Phase II SBIR contract, the company had already released the first commercial edition of TracePro and taken on two more engineers.

In 1995, Goddard Space Flight Center awarded the company another SBIR contract to develop software for end-to-end modeling and evaluation of electro-optical systems. Freniere says market analysis didn't warrant commercialization of that product, but aspects of it, such as calculation of diffracted light, were incorporated into later versions of TracePro.

A major key to the software's success was its compatibility with CAD programs, such as AutoCAD and SolidWorks, he says. To accomplish this, the company licensed the geometry engine at the heart of these modeling programs and built its software around it. "We were the first ones to do that, and it really helped us succeed," Freniere says.

This is what allows the user to import any three-dimensional model from a CAD program, rather than having to build the model in TracePro.

Another factor in the software's success was its wide applicability. "A lot of things we use to do stray light analysis can be used in other markets," says Michael Gauvin, Lambda's vice president of sales and marketing. "Anywhere you're trying to see what light is doing, we've added those functions to TracePro."

Benefits

TracePro's largest market is in optimizing overhead lighting designs, from street lamps to offices and retail spaces. The program is used to create virtual prototypes

TracePro can be used to optimize solar collectors like those pictured here, helping to determine where they should be located and how they should be angled.

Image courtesy of David Saddler

Automakers use TracePro to model dashboard displays. In the inset, the program predicts the behavior of light rays through a computer-aided design of a speedometer needle.

of lenses that can be snapped over a given light-emitting diode (LED) configuration to ensure that it will distribute light in the precise output the designer wants, Gauvin says.

Another popular application is the design of light pipes for electronics. These plastic tubes carry light from LEDs on a circuit board to indicators on the device's exterior, which might show that the machine is on or make a button easy to locate. These often use a complex geometry to guide the light along their length. "Our optimizer helps you create the shape of that light pipe to create the output desired by the illumination engineer," Gauvin says.

Engineers designing solar collectors, which use mirrors to focus sunlight to be turned into electricity, can also use TracePro to determine where mirrors should be located and how they should be angled and bent to maximize their solar output. A feature in the program uses nationwide sunlight exposure data to predict solar radiation levels, taking atmospheric turbidity into account, at any location for any given time of year at specified intervals.

"We have written many, many utilities specifically for these different markets," Gauvin says.

In the medical and life-science industries, light can be used for a range of noninvasive health-monitoring applications. One example is the common oximeter that fits over the fingertip and monitors pulse by observing the scatter of red and infrared light in tissue to calculate the blood-oxygen levels that peak with each heartbeat. Other applications include cell imaging, tissue characterization, molecular spectroscopy, microscopy, and monitoring blood-sugar levels. In all these devices, TracePro helps engineers make decisions about the best wavelengths of light to use, what angle the light should take, where sensors should be placed, and how stray light can be reduced to get the best signal.

"We have a 3D viewer that allows you to slice up light propagation through tissue to visualize and calculate absorbed, lost, incident, and exiting energy," Gauvin adds, noting that this is equivalent to observing a slice of tissue under a microscope.

TracePro can also be used to help design laser and LED surgical devices.

Carmakers use the software to create virtual prototypes of dashboard displays, which are rendered in photorealistic detail. In recent years, the company has added the capability to view these simulations from multiple angles, for example to show what a display will look like from both the driver's

> “It’s amazing what these tools can do, and the capability just seems to keep growing as computer technology grows.”
>
> — Dennis Skelton, Goddard Space Flight Center

and passenger’s points of view. It’s an approach that saves companies money by letting them observe and optimize a system before producing it, Gauvin says.

In other applications, the program can help designers create everything from signs and lamps to cameras and telescopes. The defense industry has used it for stray light analysis for its imagers, as well as optics for missile systems.

Back at NASA, the program is still loved for its original application. Dennis Skelton, an optical engineer at Sigma Space Corporation and contractor to Goddard, says it’s still the only stray light-analysis program he knows of that’s based on the same geometry engine as CAD software. Building models in earlier programs was not only tedious and time-consuming but could result in errors that went unnoticed, he says. “Now I can often just be given a file that contains the geometry I need, and that’s about half the job.”

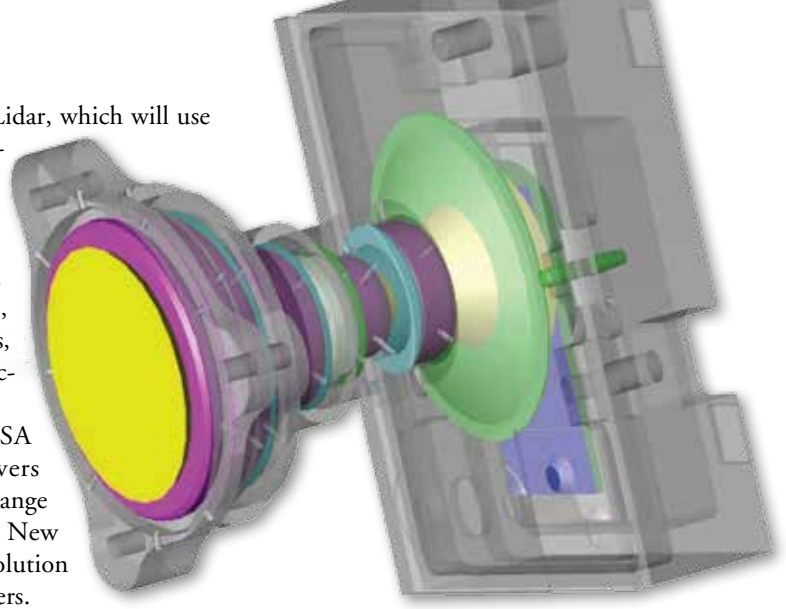
Skelton is using the program to confirm Ball Aerospace’s stray-light analyses of the James Webb Space Telescope, which is set to launch in 2018. He and Ball are now getting results within 20 percent of each other, “which is very good for stray light analysis—I never dreamed we’d get that close,” he says, noting that for a more casual analysis he would be content with agreement within a factor of two.

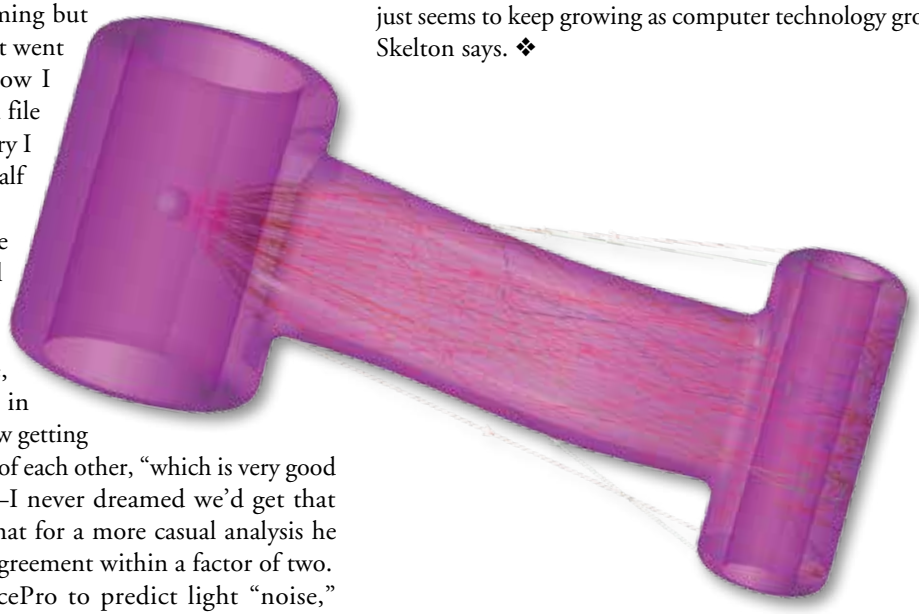
He’s also using TracePro to predict light “noise,” for example from clouds, for the receiver on the Global Ecosystem Dynamics Investigation Lidar, which will use laser pulses to map Earth’s forest densities from the International Space Station. He used it for a similar purpose on the Advanced Topographic Laser Altimeter System aboard the Ice, Cloud, and Land Elevation Satellite-2, which is measuring the polar ice sheets, as well as other topographical characteristics.

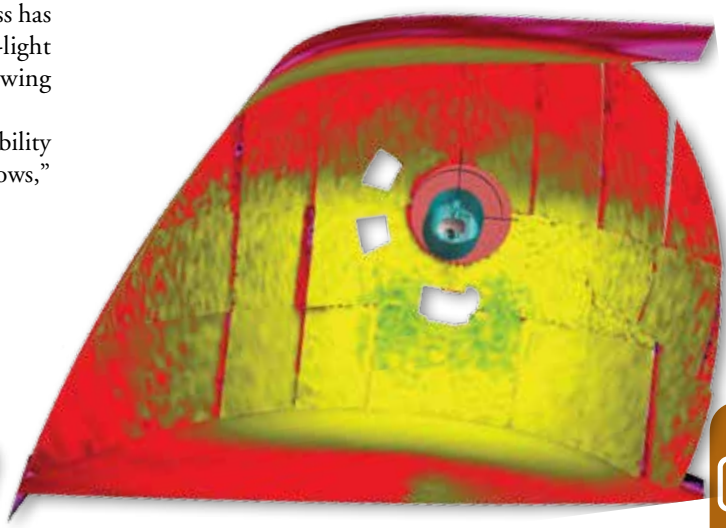
TracePro has also helped NASA design cameras for the Mars rovers Spirit and Opportunity, the Long Range Reconnaissance Imager aboard the New Horizons probe, and the Galaxy Evolution Explorer space telescope, among others.

Lambda now has 15 employees, thousands of TracePro customers, and about six times the revenue it had when TracePro was first released. Much of this success has been the result of taking what was originally a stray-light analysis program and repurposing it for an ever-growing number of industries.

“It’s amazing what these tools can do, and the capability just seems to keep growing as computer technology grows,” Skelton says. ❖







Originally created to predict and eliminate stray light in the Jet Propulsion Lab’s (JPL) imagers, TracePro has found dozens of applications across a multitude of industries. In the lower left image, the program predicts the behavior of light rays running through a link rod. In the upper middle image, JPL has reapplied the software to its original purpose: TracePro helped engineers predict and eliminate stray light from cameras on the Spirit and Opportunity Mars rovers, as well as to predict camera performance. In the right-hand image, the program predicts light output from a car headlight.

Connectors Link Data Networks for Orion, Industry

NASA Technology

The Orion crew capsule may resemble its Apollo ancestor on the surface, but all of its internal systems reflect nearly half a century of development since NASA's Moon missions. Among these is a 21st-century data system capable of quickly transmitting massive amounts of data throughout the spacecraft with hardware that's as light and durable as possible.

An integrated data system runs throughout Orion, says Ron Deppen, a mechanical engineer with Lockheed Martin Space Systems Company, a prime contractor for Orion. "This is the communication link between all of the electronics in the vehicle. It's not only in the crew module; it goes into the service module as well."

From NASA's earliest missions through the Space Shuttle era, crew vehicles relied on separate series of data networks connected via bundles of wires resembling a "rat's nest," says Clint Baggerman, Command and Data Handling system manager at Johnson Space Center. "You'd have a small network in one place connecting several boxes together and then a second network in a different part of the vehicle connected to the first, and a third network in another part. If the third network had to communicate with the first one, you'd have to wire those together, too."

Smith's Connectors developed high-speed data connectors for NASA that have found applications in Ethernet networks used in military, aerospace, and commercial aviation markets. It also sells spinoff products in the oil and gas industry.

Moving forward, NASA needed an upgrade and decided to go with a time-triggered, one-gigabit Ethernet network, in which tasks are timed and scheduled so as to eliminate delays in relaying commands. In the new design, "everything plugs into the master network, so anything can communicate with anything else at the lowest possible mass, with the fewest possible connections," Baggerman says.

For its new network, Johnson wanted lighter, smaller connectors that could transmit large amounts of data and survive the harsh conditions of space travel, criteria that existing connectors couldn't meet. The connectors used on other networks were either too big and bulky or couldn't provide the performance the Agency needed.

"We went out to a handful of companies and said, OK, who's got the best design?" Baggerman says. Johnson worked with both Lockheed and Honeywell Aerospace, the contractor responsible for Orion's flight-management systems, to review submissions from connector manufacturers.

NASA also wanted connectors with a higher impedance rating than the standard for communication networks, which would allow more data to be transmitted at lower voltages, so they had to be specially built, Deppen says. "Of course, the connectors had to meet the very high environmental requirements we have for the Orion program," including the ability to withstand takeoff, aquatic landings, and the violent jettisoning of the crew if the launch is aborted.

Technology Transfer

Five companies responded to NASA's call for submissions, but one quickly pulled ahead of the rest.

Smiths Connectors, a part of the Interconnect division of London-based Smiths Group PLC, is located in Costa Mesa, California. The branch specializes in electronic components for harsh environments, designed to withstand the high vibration and extreme temperature fluctuations faced by spacecraft and aircraft alike, says Mike Carlson, global market vice president for space and oil and gas for the company. While another company also made it through the first round of review, the ruggedized D-sub miniature connectors provided by Smiths Connectors proved most capable of meeting NASA's requirements.

"They chose ours for its mechanical ruggedness, its electromagnetic shielding capability, and its electrical performance," Carlson says. The initial interactions with NASA took place in 2010, and over the next five years the company worked under a subcontract to Lockheed to design and develop connectors qualified for Orion's first crewed flight, scheduled for 2018.

As expected, the connectors made it possible for Orion's data system to transmit more data than the network used in the Space Shuttle era while also eliminating extraneous signal noise, which can cause data loss, especially at the low voltage levels the system is designed for. Orion's first test flight in December 2014 utilized the connectors, which performed perfectly, Baggerman says. "We've tested them on Exploration Flight Test 1 so far, and they worked flawlessly. With any luck, they got the design right the first time through."

Before the design for Orion's connectors was even finalized, though, Smiths Connectors leveraged the technological advances it had made through its NASA work into a broader offering for more commercial applications.

Benefits

With NASA now a satisfied customer, Smiths Connectors made some additional modifications and released the High-Speed Ruggedized D-Sub connector to industry in July 2015. Carlson says the company is courting customers in other demanding fields, touting the connectors' ability to endure harsh environments and quickly transmit large amounts of data.

"The real crossover for this product line is that it's also used in Ethernet backbones," he says. "We have found applications for it in military aerospace and the commercial aviation market. That's the first appeal for it."

In aviation, the industry is working with "a more distributed architecture, putting sensing equipment closer to where an operation takes place—near the wings or near the engine, versus just in the fuselage—where it sees very high levels of vibration," Carlson explains.

The oil and gas industry has similar needs, as its equipment has to withstand the high pressures and vibration of drilling into hard ground. There's also growing interest from rail companies, whose entertainment and communication systems on heavily vibrating trains use massive amounts of data.

"The trend is that all markets are requiring higher levels of vibration, and that's why it's gaining mass market appeal," Carlson says.

The High-Speed Ruggedized D-Sub connectors have proven capable of supporting data networks up to and above 500 gigabits, he says.

"Space remains a key market for Smiths Connectors, as it provides the opportunity to create new solutions for extreme environments and technological challenges and then to develop those technologies into product offerings for multiple other markets, helping to continue the growth of our company," Carlson says. ❖

This 2013 test of Orion's avionics systems shows some of the capsule's complex wiring. Smith's Connectors developed rugged, reliable devices to move large amounts of data around the spacecraft, even in extreme environments.

Scheduling Software Plans Public, Private Space Missions

NASA Technology

When Alex and Ella Herz were working at Johnson Space Center in the late 1980s and early '90s, it wasn't the easiest time to plan payloads for spaceflight.

"It was the heyday of flying a lot of missions on a single Shuttle flight," says Mark Kirasich, who oversaw Johnson's payload operations at the time, noting that one flight might carry two or three primary payloads in the bay and a dozen more in the mid-deck. "Scheduling and keeping track of where a dozen different payloads were on a given day was a challenge then."

Alex, a payload project engineer for contractor Rockwell International, worked directly under Kirasich, while Ella supported payload operations as a Rockwell software systems engineer.

Now the couple has used their experience at Johnson, and later at Goddard Space Flight Center, to create software that helps most of NASA's field centers, as well as hundreds of companies and other agencies, to schedule all sorts of space operations.

At the time, Kirasich says, payload engineers might spend an entire year preparing for a single seven-day Shuttle flight. They were just starting to get their own personal computers, and there was little in the way of scheduling software. "We would pay people to develop unique scheduling tools for various purposes."

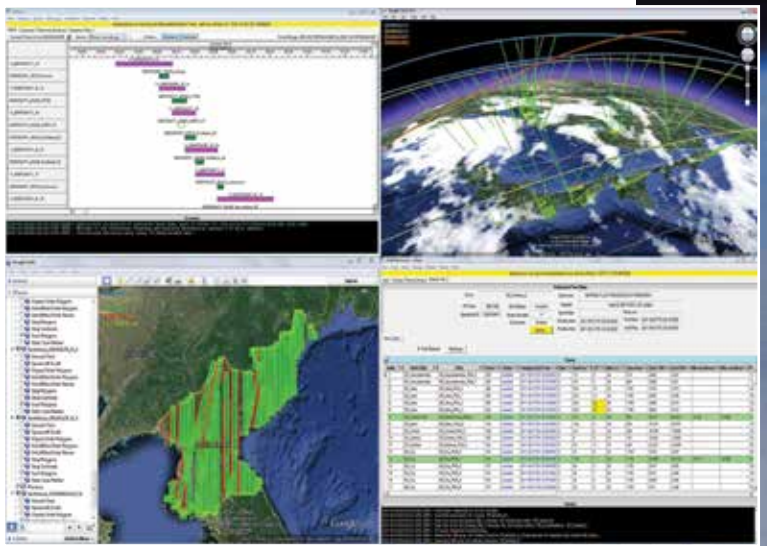
"There were timeline tools to lay down a schedule, and mission-unique tools, but they weren't reconfigurable," Alex recalls.

"For each mission it was different," Ella agrees. "We got a lot of exposure to changing requirements. But you start seeing what types of operations and what types of things come up over and over again."

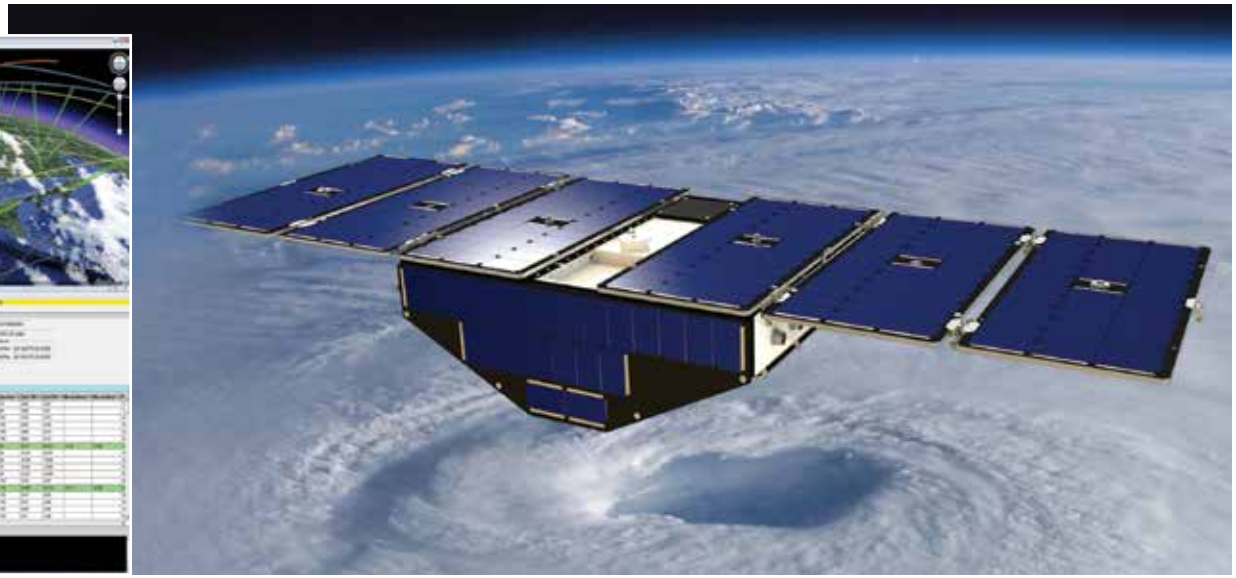
Kirasich says he remembers Alex being inclined to develop his own solutions to problems. "He was one of those who brought innovative ideas, so it doesn't surprise me to hear that they took what they learned and turned it into a new innovation."

In the mid- to late 1990s, Alex took a job as director of ground systems with Omitron Inc. at Goddard, while Ella went on to work as a quality assurance manager at L-3 Storm Control Systems. Goddard is where Alex met Doug George. They were working on ground systems for the field center's Vegetation Canopy Lidar (VCL)—planned to be the first space mission of NASA's Earth System Science Pathfinder Program—and they managed to build a control center with commercial off-the-shelf technology. They wanted to do the same for mission planning, but there were no such tools available, so they created scheduling software from scratch.

"We laid down tasks, tied them to orbital events, put them in a time-ordered table view, and color-coded for different tasks," Alex recalls. "And you've got to define



Orbit Logic's STK Scheduler, informed by its founders' experience working for NASA, is a generic, reconfigurable scheduler for space missions that generates optimized timelines based on input tasks, resources, priorities, and constraints.



Among the many NASA programs that now use STK Scheduler to build their mission timelines is Cyclone Global Navigation Satellite System, designed to improve hurricane forecasting.

your resources—equipment, satellites, subsystems, people, etc.—that will be scheduled."

But the program was coded specifically for VCL, a mission that never flew.

Technology Transfer

In 2000, the trio founded Greenbelt, Maryland-based Orbit Logic, with Alex as president, George as vice president, and Ella as chief operating officer. Their idea was to build ground control centers from off-the-shelf technology, as Alex and George had done for VCL.

"At some point, we needed a planning tool," Alex says. "Once again, we looked around and couldn't find anything."

They had developed a relationship with Analytical Graphics Inc., the company that offers Systems Tool Kit (STK), which Alex and George had used to model flight dynamics for VCL, and the two companies teamed up with another software company, Optwise Corporation, to create a generic, reconfigurable scheduling program for space operations.

They applied for NASA funding through the Small Business Innovation Research program, but researchers at the Agency turned them down. NASA said such a program wasn't feasible, as each space mission is unique, Ella recalls. "But we did it anyway."

Orbit Logic's role in the venture was to create the user interface and timeline views and coordinate scheduling activities with STK and the customized algorithms from Optwise.

The work, including the system of defining tasks, resources, priorities, and constraints to build a space mission schedule, is based both on Alex and Ella's experience scheduling payloads at Johnson and on Alex and George's creation of the scheduler for VCL at Goddard.

"If I want to communicate with a satellite four times a day from my three ground stations, that's a task. If I only want to do it when the satellite's in the sun, that's a constraint," Ella explains. "People's availability is also a constraint. Once you have all of that defined, you have to have scheduling algorithms that will generate a deconflicted, validated, optimized schedule."

Tasks are prioritized according to importance or their necessity to following tasks. If an action is dropped from the schedule, the program will reevaluate the entire agenda based on weighted factors, eliminating conflicts and reconsidering priorities, and, again, generate the most efficient schedule possible.

It then provides various formats for displaying, reporting, or even animating the new schedule.

Benefits

STK Scheduler was released in 2002, and Orbit Logic has since sold licenses for the program to around 250 customers, including almost every NASA field center and various other government agencies and companies in the United States and abroad.

Among the NASA missions now using the program is the Space Network Ground Segment Sustainment project, aimed at refurbishing the ground systems supporting the satellites that provide communications capabilities to spacecraft in low-Earth orbit. Another is the Cyclone Global Navigation Satellite System, which measures ocean surface winds to improve hurricane forecasting.

The company Orbital ATK uses STK Scheduler to schedule prelaunch, launch, and early orbit activities for many of its space missions, including its GEOStar geosynchronous communications satellites. "Before, they would have used a huge spreadsheet, and changing anything might have taken days," Ella says. "Now, you make a change and"—she snaps her fingers—"like that, it's updated." DigitalGlobe, a major provider of satellite imagery of Earth, is also a customer.

With more and more companies planning constellations of dozens and even hundreds of satellites, automated planning algorithms like STK Scheduler become essential, she says. "You cannot manually plan for that. It would take an army. We can do it in ways that humans absolutely cannot do." And as more space agencies are created, calls are coming in from around the world, she continues. "Space situational awareness is hot right now."

The software has also shown potential for many other uses. While space applications have been enough to keep Orbit Logic busy, Ella says, the company has demonstrated its effectiveness for uses as varied as classroom planning, firehouse shift scheduling, light bulb manufacturing, and systems test scheduling. Oil and gas operations are another potential market.

STK Scheduler is one of several products and services Orbit Logic offers, and Ella estimates sales and maintenance of the program represent about 5 to 10 percent of the company's business, with another 20 percent or so coming from Government contracts based on the software. "Even if Scheduler comes out to a small percentage of our business, the rest of Orbit Logic's business is also related to mission planning and scheduling software," she says.

"The STK Scheduler product is why people come to us for scheduling solutions now, even if they don't end up using it," Alex adds.

And it's a product made possible by the company's roots in the Space Agency. "That's why the business we founded is a space business," Ella says. "Because we know space from working at NASA." ❖

NASA's Space Network Ground Segment Sustainment project, refurbishing ground systems supporting the satellites that provide communications capabilities to spacecraft in low-Earth orbit, is using STK Scheduler to plan its activities. The ground network consists of three stations—two in New Mexico and this one on the island of Guam.

Power Amplifiers Boost Radar, Communications, Defense Systems

NASA Technology

Normally, state-of-the-art technology comes at a cost. But when QuinStar Technology was subcontracted in 2009 to build a power amplifier for one of NASA Jet Propulsion Laboratory's (JPL) radars, what the company delivered was not only more compact and reliable than the amplifiers typically used in such instruments but also less expensive.

Remote Sensing Solutions (RSS), the prime contractor, had issued rigorous specifications for a solid-state power amplifier (SSPA) to boost signals from a radar operating at Ka-band frequencies—a slice of the microwave spectrum between 26 and 40 gigahertz—to be used in the calibration and validation of an instrument that would one day fly on the Surface Water Ocean Topography (SWOT) mission. The project, a cooperative effort between NASA and the French and Canadian space agencies, will use radar interferometers to create the first topographical map of Earth's oceans, lakes, and rivers, determining and monitoring the global distribution of freshwater, and examining how ocean currents interplay with climate change, among other studies.

Before its 2020 satellite launch, the equipment has to be tested. So, in 2008, JPL granted the first of two Small Business Innovation Research (SBIR) contracts to RSS to design and build the Ka-Band SWOT Phenomenology Airborne Radar (KaSPAR), which is testing key SWOT instrument subsystems and measurement approach aboard a turboprop plane.

Until recently, power amplifiers for such radars have generally been tube-based, but for KaSPAR, RSS wanted a highly efficient, compact, solid-state amplifier that could operate at high altitude and only required conduction cooling. The SBIR proposal for the project notes that a state-of-the-art SSPA would not only improve the surface-mapper's performance but also open the way for such technology to fly on long-term unmanned aerial vehicle (UAV) missions. And power amplifiers have a multitude of applications, from communications to electronic warfare, so advancements could play out across a range of technologies.

The subcontractor initially hired to build the amplifier wasn't able to complete the work, so RSS turned to Torrance, California-based QuinStar, which already had a history of pushing the boundaries of SSPA technology for other Government agencies.

Technology Transfer

There was little money left on the SBIR contract, and QuinStar, eager to advance its SSPA capabilities, invested a chunk of its own money to develop an amplifier of unprecedented efficiency.

"The one we developed is very highly advanced and very potent," says Naresh Deo, vice president of business development for QuinStar, adding that the technology is "unique and unprecedented and can serve some purposes it couldn't before."

An SSPA routes a signal through an array of amplifiers, each of which boosts its portion of the signal, and then recombines the channels into a single, intensified output. The problem is that power is lost as the signal is recombined, with more channels meaning more energy dissipated when the signal is funneled back into a single pulse.

"What's different about our power combiners is they're extremely efficient," Deo says, noting that, while most SSPAs lose around 20 percent of their amplified energy at recombination, QuinStar's now lose only 8 percent.

Following delivery of the KaSPAR amplifier, RSS ordered another SSPA from QuinStar for JPL's Airborne Glacier and Land Ice Surface Topography Interferometer. "With that success, NASA started ordering all their SSPAs from us," Deo says.

QuinStar and NASA shared the cost of developing a high-power W-band solid-state power amplifier for Goddard Space Flight Center's Cloud Radar System, which flew on the ER-2 high-altitude Earth science aircraft as part of the 2014 Integrated Precipitation and Hydrology Experiment. The power amplifier helped researchers collect data on precipitation distribution in clouds to improve understanding of precipitation over mountainous terrain, such as this supercell thunderstorm, photographed from the ER-2 as it passed over North Carolina on the evening of May 23, 2014.

The company has provided similar amplifiers for Goddard Spaceflight Center's High-Altitude Imaging Wind and Rain Airborne Profiler and for Goddard's Dual-Frequency Dual-Polarized Doppler Radar and is currently carrying out SBIR work for both Goddard and JPL. Nowadays, Deo says, "We're always building some amplifier for NASA or its contractors—pretty much constantly."

Meanwhile, innovations the company pioneers through its NASA work also advance its commercial offerings.

Benefits

Lihua Li, an engineer with the Airborne Science Program at Goddard who has worked with QuinStar on a number of projects, says there are good reasons why NASA would prefer SSPAs to tube-based amplifiers. The solid-state technology does not require high voltage and is lighter, more compact, and more reliable than its predecessors, he says. "It's a new technology and has been developed quite fast in recent years."

Goddard intends to develop an SSPA-based radar and install it on the International Space Station (ISS) to monitor Earth's atmosphere. The QuinStar SSPA planned for this radar has a volume of about 650 cubic inches and weighs seven pounds, Li says. A comparable tube-based predecessor had an approximate volume of 3,200 cubic inches and weighed between 30 and 40 pounds.

Li says tube amplifiers are not only bulkier but require a high-voltage power supply and modulator units that need pressurization in space to avoid electrical arcing.

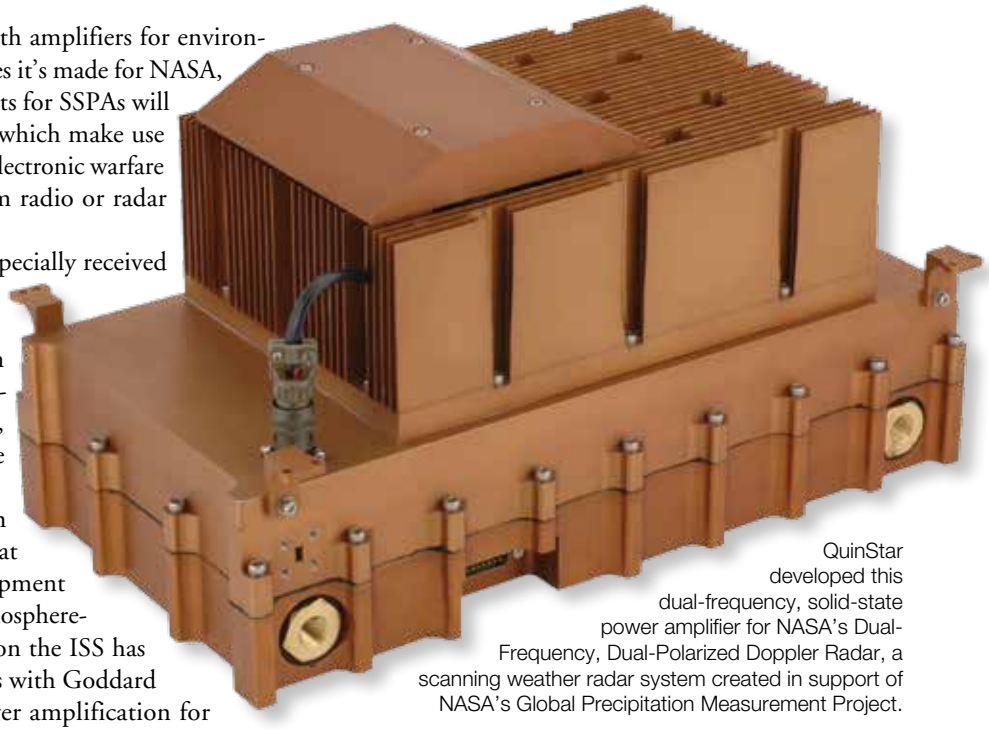
All these advantages are crucial to space and aeronautic applications, where power is limited and weight and size are kept to a minimum, Deo says. This is why SSPAs opened the way for long-term UAV missions that wouldn't have been feasible for a heavy, bulky tube amplifier-based radar, for example. "NASA had been denied access to quite a bit of data and flight time because the tube amplifier-based radars were too big," he says. "With our lower-weight, smaller, more compact SSPA, they could build a compact radar that fits into a small drone."

Even in a ground-based application, he says, SSPAs present advantages in price and reliability.

QuinStar chose to begin with amplifiers for environmental research, such as the ones it's made for NASA, but Deo says the biggest markets for SSPAs will probably be communications, which make use of microwave frequencies, and electronic warfare such as devices that overwhelm radio or radar receivers with powerful signals.

He says the company has especially received interest in SSPAs from the Navy, the of Massachusetts Institute of Technology Lincoln Laboratory, and satellite companies. "The interest was there, but now they realize we have the technology," he says.

The company's work with NASA continues to advance that technology. QuinStar's development of a prototype SSPA for the atmosphere-monitoring radar to be flown on the ISS has been funded by SBIR contracts with Goddard and promises to improve power amplification for transmitters operating in the W-band of the electromagnetic spectrum, microwaves with frequencies between 75 and 110 gigahertz.



QuinStar developed this dual-frequency, solid-state power amplifier for NASA's Dual-Frequency, Dual-Polarized Doppler Radar, a scanning weather radar system created in support of NASA's Global Precipitation Measurement Project.

QuinStar also shared the cost of developing a high-power W-band SSPA for Goddard's Cloud Radar System, which flew on NASA's ER-2 high-altitude Earth science aircraft and collected valuable data as part of the 2014 Integrated Precipitation and Hydrology Experiment.

The communications industry has begun to show interest in operating at W-band frequencies, which offer more bandwidth than the lower frequencies usually used for communications. "You could potentially feed more channels into that bandwidth to carry more signal information," Li says, adding that W-band transmitters are already used for vehicle collision-avoidance systems, surveillance sensors, and, in defense applications, target-seeking. "It's a very promising technology, and we're happy to work on it with QuinStar," Li says.

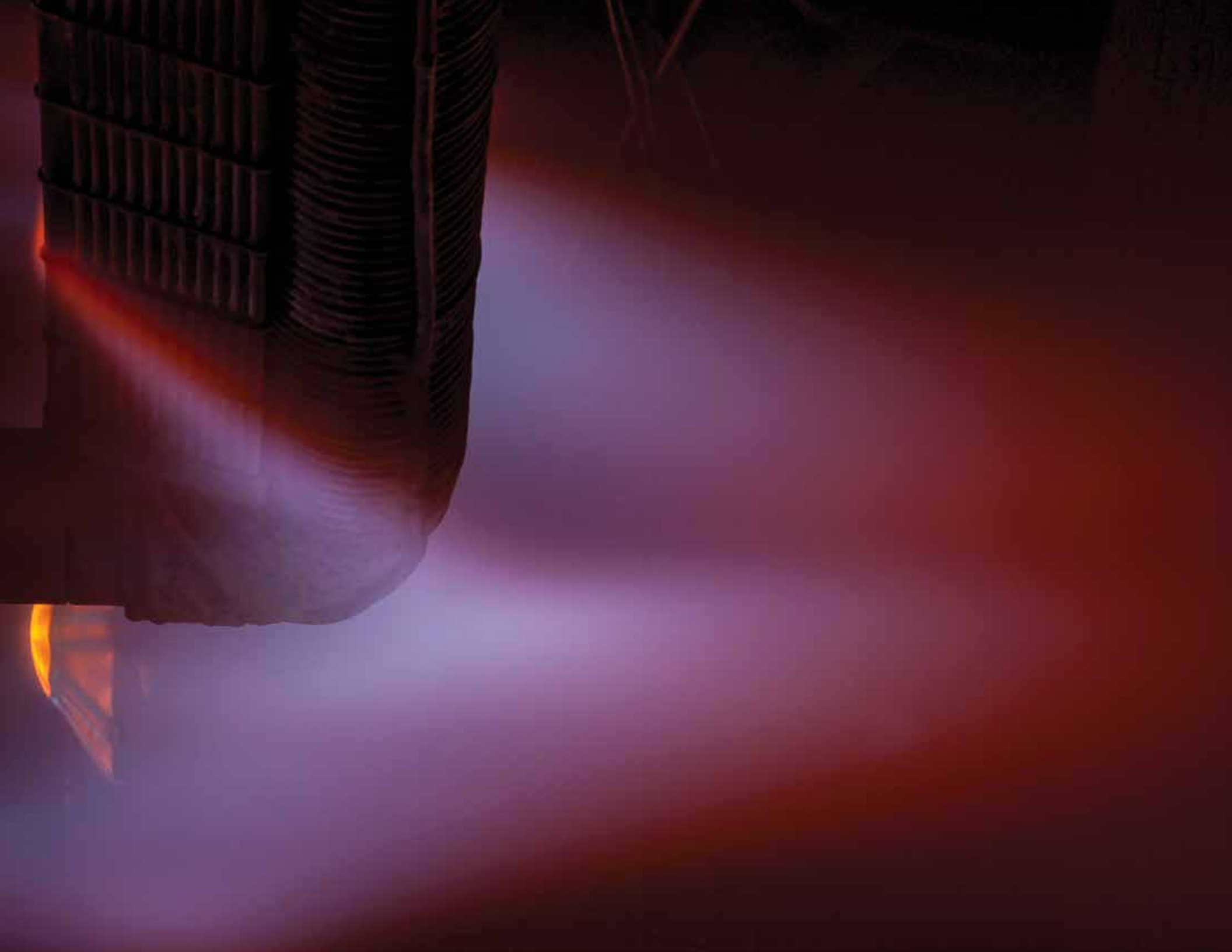
Another set of SBIR contracts with JPL is letting QuinStar develop gallium nitride chips for an SSPA to power Ka-band communication links. The technology promises a 5- to 10-fold greater power density than amplifiers made with more traditional semiconductors like gallium arsenide. NASA is interested in the potential power savings for airborne and space remote sensing applications, but the technology would also have broad applications across satellite communications, weather and environmental monitoring radars, aircraft landing systems, security and surveillance radars, and helicopter collision-avoidance radars.

"The technology developed through those SBIRs, there's a pretty wide potential for the commercial market," Li says, noting that QuinStar is at the leading edge of solid-state amplifier technology for transmitters operating in both the widely used Ka-band and the emerging market of the W-band.

"QuinStar's SSPA technology has served our research applications very well, and there are many promising opportunities to transfer this technology to commercial products," he says. ❖

Industrial Productivity

To explore the frontiers of space and other worlds, NASA often has to engineer technologies unlike anything seen before. It might partner with a company to produce 3D-woven heat shields, for example, or to create a vibration table large enough to test a space telescope the size of a tennis court. Other innovations come about from NASA's unique facilities, such as a laboratory for testing how materials perform when exposed to space. Commercial spinoffs from these and other endeavors are playing a big part in our Nation's industrial base.



3D Weaving Technology Strengthens Spacecraft, Race Cars

NASA Technology

Weaving processes created millennia ago have helped create some of the most cutting-edge technology on NASA's Orion spaceship, helping shield heat for humans who may one day ride all the way to Mars and back.

When Orion leaves Earth orbit and travels deeper into space, it's going to have to go fast. Likewise, it will be speeding along when it returns—generating searing heat as it smashes into our atmosphere and slows down for a safe landing.

One spot on Orion's heat shield proved particularly challenging for the engineers designing it: it needed to be not only a great insulator but also structurally strong. "Most of the heat shield is a kind of low-density material that's very good at insulating the heat. That's the main thing it has to do, but it's not a very strong material," explains materials engineer Jay Feldman, technical lead for the 3D Multifunctional Ablative Thermal Protection System (3D-MAT) at NASA's Ames Research Center.

But there are points across the surface of the heat shield that must connect the crew capsule to its service module and, ultimately, the rocket. "At these points, you have to use a very strong, robust material," Feldman says.

Called compression pads, these disc-shaped connection points were made of steel and carbon fiber composite for Orion's first test flight to low-Earth orbit, which launched in late 2014. Unfortunately, the pads conducted a lot of heat, says Feldman. "It was just manageable for that first flight test, but once we were going farther and coming back faster and hotter, it would have pumped too much heat into the vehicle."

Luckily, Feldman and other engineers at Ames were already working with partners at high-tech weaving company Bally Ribbon Mills on next-generation heat-shielding material. Together, they were developing a three-dimensional quartz-fiber composite, woven using classic shuttle looms upgraded for the modern era. They

Orion, NASA's new exploration spacecraft, being prepared for its first flight test in 2014. The 10-inch holes on the bottom of the spacecraft hold compression pads designed to be very good insulators while also very structurally strong. On the next test flight, these pads will be made from a 3D quartz composite woven by Bally Ribbon Mills (inset).

quickly realized this material could be perfect for the Orion compression pads.

Unlike the previous compression pads, made by layering together two-dimensional woven materials, the Ames team saw benefits in using three-dimensional woven composites. "When you have fibers going in all three directions, it's very, very strong," explains Feldman. "And we can also tailor the composition so it has relatively low thermal conductivity."

Technology Transfer

Bally Ribbon Mills, in Bally, Pennsylvania was a natural partner for the project. A leading U.S. manufacturer of high-tech two- and three-dimensional textiles, the company's client list includes the U.S. Air Force, Formula One racing teams, and biomedical companies.

"At NASA, we specialize in a lot of things. We have a lot of knowledge. But we don't do weaving. Weaving is such an old art, and the weaving industry has been there much longer than NASA," says Ethiraj Venkatapathy, project manager and chief technologist for the Entry Systems and Technologies Division.

The firm's expertise extends back to 1923, when the family-owned company started out weaving silk hat bands.

"The first generation was just trying to build a business. They wove what was available, which was silk," explains Mark Harries, part of the fourth generation of his family to run the textile company. "The next generation took the reins from my great grandfather, and they were still growing the business, but with man-made fibers." As the industry changed and mass textile production moved increasingly overseas, many nearby mills were closing, but Bally Ribbon continued to evolve.

"Then the third generation came along: my father and cousin," Harries says. "We started doing more things with new fibers, new machines, all of a sudden we're hiring engineers and using computers to keep track of things."

"That's when we really found our niche," Harries adds. "To keep the company afloat and stay in business, they started doing more smaller-run, custom items"—like the project with NASA.

With some seed money from Ames internal research and development, NASA and Bally Ribbon Mills started building 3D woven prototypes for thermal protection systems. After promising early work, Venkatapathy and Feldman got additional funding from NASA's Space Technology Mission Directorate and through Small Business Innovation Research contracts. When the company and NASA realized the technology might solve the Orion compression pad issues, additional funding came through the Game Changing Development Program.

The textiles NASA needed were thicker than what Bally Ribbon Mills had woven before, explains senior textile engineer Curt Wilkinson. "Bally's limit had been two inches until this project. So we needed to modify and design special equipment in order to achieve the three-inch thickness." NASA also wanted the same number of fibers going in all three directions, to improve compression strength.

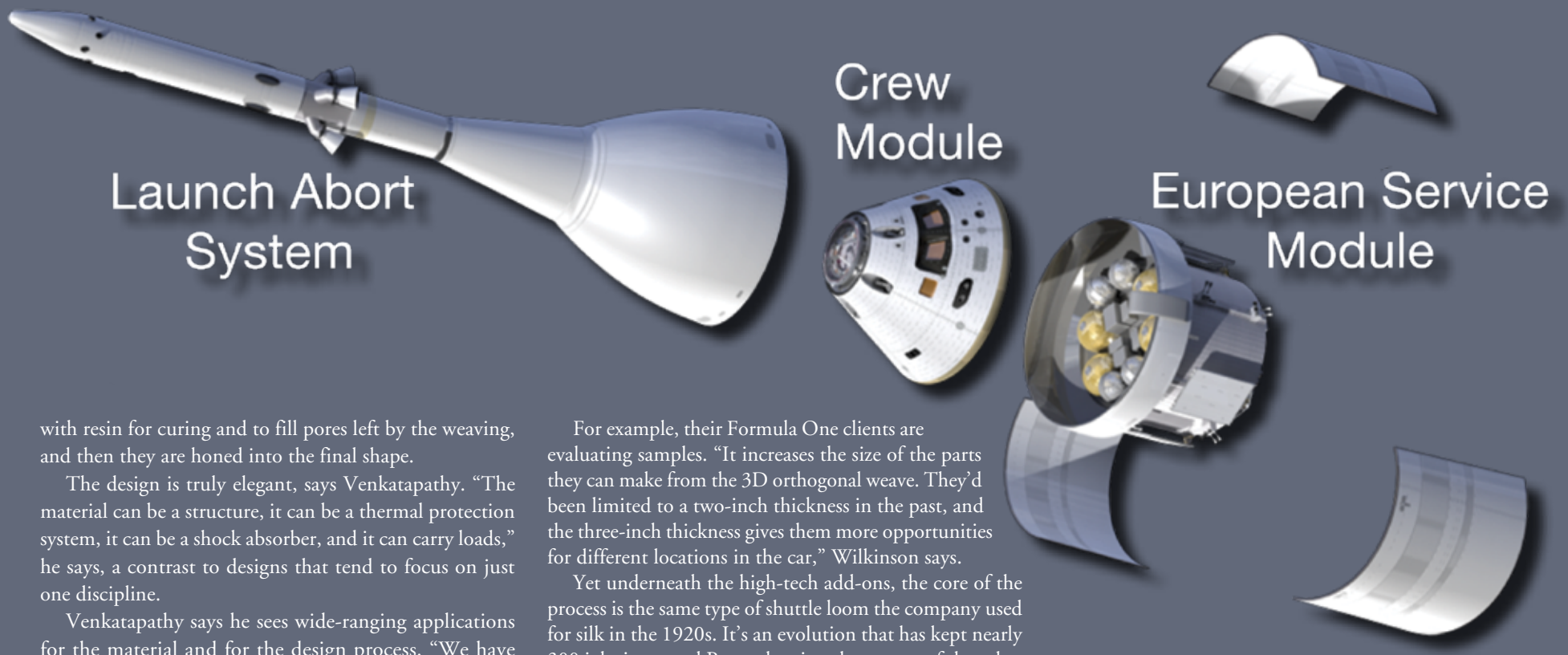
The partnership and the resulting material have generated a lot of excitement at NASA, prompting a January 2015 visit to the mill by NASA Administrator Charles Bolden, who declared: "From this day on, the path to Mars goes through Bally, Pennsylvania."

Benefits

Bally Ribbon Mills uses a technique called 3D orthogonal weaving, in which the fibers go in three perpendicular orientations and are perfectly straight. "That is the strongest type of 3D weave you can produce," Feldman says.

The threads are made of quartz, which is an excellent insulator, Wilkinson says. "It also has very good dielectric properties for transmitting electrical signals through it."

The final product "is like a brick," Wilkinson explains. "We are packing a lot of fiber in there. Many times during the development, we were unsure if we could actually pack the fiber volume that they were looking for." Once they're woven, the blocks get sent to another company to be infused



with resin for curing and to fill pores left by the weaving, and then they are honed into the final shape.

The design is truly elegant, says Venkatapathy. "The material can be a structure, it can be a thermal protection system, it can be a shock absorber, and it can carry loads," he says, a contrast to designs that tend to focus on just one discipline.

Venkatapathy says he sees wide-ranging applications for the material and for the design process. "We have demonstrated that for a very complicated region, a simple solution has evolved to meet the requirement. We can extend that to other places as we go toward human Mars or other very complicated human missions."

Already the designers of Orion are looking at other spots on the vessel where the 3D-MAT material may be incorporated. And outside NASA, Government agencies and aerospace companies have expressed interest for thermal protection systems, including the Department of Defense. "They are already starting to fund new development with Bally Ribbon as a result of our NASA work," notes Feldman.

The work for NASA has also increased the product line the company offers in more frequently used materials, like carbon fiber, to its long-standing clients, because the new equipment they designed enables thicker and denser weaves.

For example, their Formula One clients are evaluating samples. "It increases the size of the parts they can make from the 3D orthogonal weave. They'd been limited to a two-inch thickness in the past, and the three-inch thickness gives them more opportunities for different locations in the car," Wilkinson says.

Yet underneath the high-tech add-ons, the core of the process is the same type of shuttle loom the company used for silk in the 1920s. It's an evolution that has kept nearly 300 jobs in central Pennsylvania, where most of the other textile mills have long gone out of business.

"We incorporate modern electronic components, and we also build and incorporate our own take-up systems, but the loom itself is extremely old," Wilkinson says. The fundamental process has been unchanged for millennia: "Using the same age-old steps of weaving, we're now weaving material that's going to go to Mars." ❖

The compression pads attach where the crew module connects to the service module. The 3D woven quartz composite designed by Bally Ribbon Mills and Ames researchers is much stronger than the layered 2D composites used in the first test flight.

NASA Administrator Charles Bolden inspects a loom at Bally Ribbon Mills during a January 2015 visit to Bally, Pennsylvania. Bally Ribbon Mills uses weaving processes created thousands of years ago, with some high-tech updates, to produce modern, high performance 3D composites that will help NASA send humans and robots further into the solar system.

"From this day on, the path to **Mars goes** through **Bally, Pennsylvania."**

— NASA Administrator Charles Bolden

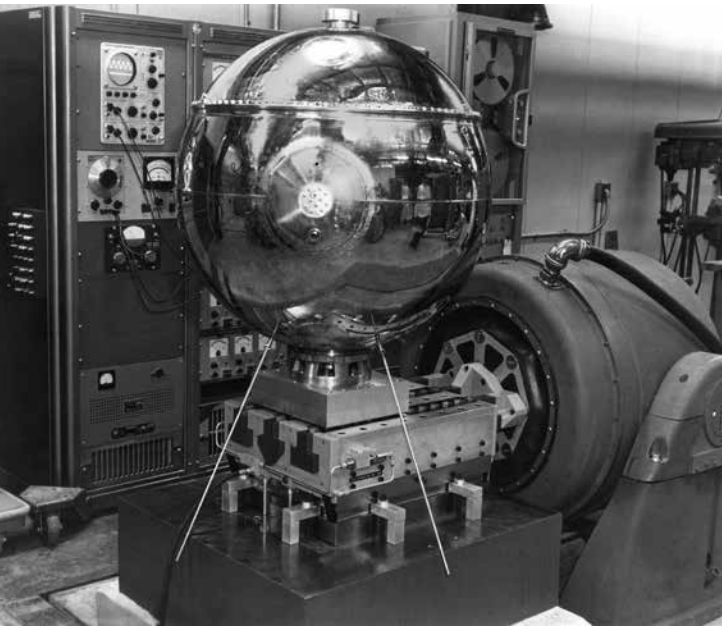
Vibration Tables Shake Up Aerospace, Car Testing

NASA Technology

When handling a multi-billion-dollar space telescope, you want to be pretty careful. Unless it's your job to shake it with 100,000 pounds of force, that is.

The James Webb Space Telescope, currently under construction at the Goddard Space Flight Center, is planned to succeed the Hubble Space Telescope in 2018. It has a bigger primary mirror, can see further, and will travel deeper into space than its predecessor, sending back images of never-before-seen phenomena to help scientists better understand how galaxies, stars, and planets form.

The 14,300-pound telescope is equipped with 18 separate, intricately engineered mirrors and carefully calibrated sensors, all of which have to survive a rocket launch and bruising ride through the atmosphere at 32 times the speed of sound. In order to ensure the hardware can survive—before it gets to its destination a million miles away, where it would be nearly impossible to fix—engineers will strap the telescope to vibration tables and shake it in every direction. Hard.



The Vanguard 1, one of the first satellites ever launched into orbit and the oldest satellite still orbiting Earth, was tested on a vibration table built by Team Corporation in the late 1950s. Innovations incorporated into those early devices are still used in Team's commercial products to this day.

It's a process every spacecraft and satellite has gone through since the Space Agency first began sending satellites into orbit in the 1950s. To test Webb, NASA once again turned to a company that has been instrumental in the Agency's vibration testing since the beginning: Burlington, Washington-based Team Corporation.

Goddard commissioned and installed two brand-new vibration testing devices. At 11 square feet, they are nearly twice as big as the one the center had in its basement vibration lab, also built by Team, and the new tables are engineered in some special ways as a result of their size. "Our shakers downstairs are capable of being reoriented. The new shakers have a dedicated system to do the horizontal and a separate system to do the vertical," explains Brian Ross, lead structural dynamic test engineer for the new telescope.

"The horizontal system is more or less the same, just a lot bigger, but the vertical system is completely different. It actually has two shakers that drive the table, and then it has quite a lot of structure surrounding the table to help react out, or counterbalance, the large loads." Each system generates up to 100 vibrations per second, mimicking the forces the telescope will encounter on launch day.

One of the new requirements Team had to meet was for a "soft stop," ensuring that if anything went wrong during the testing, the vibrations wouldn't stop too abruptly. "Usually, the systems are designed to protect themselves first," explains Ross. Most of the time, the item being tested is one of many and easier to replace than the machine itself, which can cost millions of dollars.

That calculation is reversed, of course, with items like the Webb telescope, whose total cost is projected at around $8 billion. If the machine stops abruptly, that could transfer a shock to the telescope, causing damage. So at NASA's request, Team built in a system that would ensure the shaking would allow at least four-tenths of a second to slow down before stopping: not much, but enough to protect the telescope.

> "We've evolved this in-house knowledge NASA has been fundamental in helping us develop, and we bring that to bear on all our products."
>
> — Curt Nelson, Team Corporation

Technology Transfer

In the early days of the aerospace industry, certain aspects of the air and spacecraft development process remained fairly primitive, and one of those, explains Team's Curt Nelson, was the testing procedure. "Basically they built it, stuck someone into it, flew off, and saw what happened," says Nelson, who is in charge of North American military and aerospace sales for the company.

Engineers recognized the need for better preflight testing, and Vern Tauscher, who started working in aviation after World War II, devised a machine to provide powerful vibrations, based on reverse engineering of a German rocket. "He developed our very first product, the HydraShaker," Nelson says. "We still build variations of that device every day. Bigger, smaller, but the core technology is basically the same."

Tauscher founded Team, which stands for Tauscher Engineering and Manufacturing, in 1954. His first clients were in the military aviation industry, but when NASA started testing spacecraft, it also turned to Tauscher. Needing improved equipment for the demands of

Team Corporation designed and built a system to mimic the forces this cannon turret, made by BAE Systems, would experience when driven at high speed over rough terrain. The testing showed 147 different hardware failures that the company was able to correct before the machine was ever deployed in the field.

spacecraft, Team invented under a NASA contract what it calls Model 1830 T and V bearings, which are stiff and frictionless and can carry both tension and compression.

The first shaker using these bearings was delivered to NASA and was used to test the Vanguard 1 satellite, one of the first U.S. satellites ever launched into orbit. Today thousands of these T and V bearings are used around the world in vibration testing equipment.

Benefits

Team specializes in high-end custom equipment, solving problems in ways that haven't been done before, Nelson says. Its machines can be found in pretty much every Department of Defense and Department of Energy lab and are used by companies including Boeing, Lockheed Martin, and Northrop Grumman to test equipment ranging from tanks and airplanes to nuclear warheads. The machines also test a variety of more everyday objects, from cars to yogurt containers.

In addition to a rocket launch, these devices can recreate conditions of a bouncing road or a massive earthquake. It's all aimed at determining just how well a structure will hold up in real life in a moment of extreme stress or over a lifetime of wear and tear.

Updates on those same hydrostatic bearings first designed for NASA in the 1950s can still be found in a number of the vibration testers, including ones used by some of the world's largest car companies. Team equipment tests individual components, from engine valves all the way up to passenger seats, as well as what's called "end-of-the-line" testing, when the whole car is put together.

Using four small vertical shakers, one under each car wheel, automakers like Ford Motor Company test how well the fully-assembled car or light truck will perform once it hits the road: will it squeak and rattle? Will the parts hold up during tens of thousands of miles of highways and country roads?

Team is working up a massive new proposal using these four-poster shakers for a company looking for "super high performance," Nelson says, a project that could be worth $75 million if fully implemented. He is cautiously optimistic that the company will get the job, he says, a result he attributes directly to the expertise Team built in its work with NASA.

"We've evolved this in-house knowledge NASA has been fundamental in helping us develop, and we bring that to bear on all our products." ❖

The James Webb Space Telescope, set to succeed Hubble in 2018, is equipped with 18 separate, intricately engineered mirrors and carefully calibrated sensors, all of which will require testing before being sent to space. Here the mirrors emerge from deep-freeze testing at Marshall Space Flight Center. Later, once the telescope is fully assembled, it will be shaken on super-sized vibration tables, custom built by Team, to ensure it can withstand the forces of a rocket launch.

Astronauts Instruct Newcomers on Peculiarities of Spaceflight

NASA Technology

Few people are more thoroughly trained for their work than astronauts. After all, their already-complex work is carried out in an unforgiving environment that plays by completely different rules than life on Earth. The lack of gravity, the alternately searing and freezing vacuum of space, and the mechanics of piloting and docking a vehicle while orbiting at more than 17,000 mph all require preparation that very few people will ever need.

But for the many thousands of nonastronauts who work in the space industry—whose numbers are growing now that space exploration is spilling into the private sector—some of that training would come in handy.

"There's been no place you can go to get formal training in how things work in the spaceflight industry," says Scott Glaser, vice president of operations for the International Flight Test Institute (IFTI) in Mojave, California. Beginning in 2016, IFTI is changing that with the help of two former NASA astronauts, retired Air Force Colonel Rick Searfoss and retired Navy Commander William "Billy O" Oefelein.

Even for an astronaut, Oefelein has had a lot of training. Members of the Astronaut Class of 1998, he and his crew started their mission training at Johnson Space Center early due to the complexity of their planned International Space Station (ISS) assembly operation. And when the Space Shuttle Program was suspended for two and a half years following the Space Shuttle Columbia disaster in 2003, they just kept training.

> "It's kind of hard to go get a degree in spaceflight. This gives you a lot of the practical knowledge you need to get into your job and be productive from day one."
>
> — William "Billy O" Oefelein, International Flight Test Institute

"The timing was good and bad in a sense," Oefelein says, noting that he ended up training for almost five years before finally piloting Space Shuttle Discovery to the ISS in December 2006 on the STS-116 mission.

All that practice paid off. From the outset, the mission was considered one of the most difficult NASA had ever attempted, and that was before things went wrong.

Three spacewalks were planned for the mission, during which the astronauts would install the station's new P5 truss segment—part of the assembly that holds the port-side photovoltaic arrays—and rewire all of the station's power and thermal control systems into their permanent configurations in a process never attempted before. Half of one of the solar arrays would also have to be retracted to make way for a rotary joint to be activated, allowing newer arrays to track the sun.

A mission overview published before launch called the effort "the most choreographed assembly flight to date between the Shuttle and station crewmembers and flight

Scott Glaser, vice president of operations for the International Flight Test Institute (IFTI), center, and former astronaut Rick Searfoss, right, speak with future spaceflight course participants in front of the institute's T-38 Talon supersonic jet trainer.

controllers in Mission Control." The in-cabin choreographer for all the mission's spacewalks was Oefelein.

"We figured something was going to go wrong," he says. "But what went wrong wasn't what anyone expected to go wrong."

Toward the end of the mission, the solar array that needed to retract refused to fold. With all the work they'd done now at risk, the astronauts and flight controllers had to create new procedures for a fourth spacewalk, insulate a spacesuit against electricity, develop a new tool, and figure out what was wrong with the array—all in one day.

Two planes from IFTI's fleet fly over the Mojave Desert, where the institute is located. Top is a MB-326 Impala used for high acceleration and unusual attitude flight, and below is a Rockwell Sabreliner, used for the zero-gravity experiences that are part of the organization's spaceflight curriculum.

"We had confidence in our abilities," Oefelein says. "I think the ground crew was losing more sleep than we were."

The last-minute improvisations were a success, and the incident highlighted not only the importance of training but the difference between what Oefelein calls task-based training and skills-based training. "We developed the skill, without us really knowing it, to be able to adapt to a contingency we didn't train for."

Technology Transfer

Oefelein and Searfoss—who piloted two Shuttle missions and served as commander on another—have both used their experience as military test pilots and on the Space Shuttle to help teach IFTI's test pilot course since the company launched in 2014. Now, as instructors for the school's new spaceflight course, they bring the full weight of their NASA training and flight time to bear.

It's training that can only really be offered by the relatively few people who have direct experience of operations like docking a vehicle in orbit or using tools in a zero-gravity environment, where Newton's "equal and opposite reaction" can mean inadvertently flipping head over heels or sailing backwards across a module.

The course, which typically runs two weeks, is not intended for future astronauts so much as for the many other people involved in spaceflight, says Glaser. "It's much more focused for people making it happen on the ground than on the crews."

These could be design analysts, test engineers, program managers, technicians, or a host of others who need an understanding of spaceflight. The first week of the course is classroom-based, covering subjects from orbital mechanics to legal regulations and from spacecraft design and testing down to administrative paperwork. The optional second week consists of hands-on exercises that apply concepts taught in the first week, with students designing a payload and planning and carrying out a mission in zero gravity and high gravity, simulated by flying a plane in parabolas. The material, Oefelein says, is based largely on NASA's astronaut candidate training.

Glaser emphasizes that the duration and curriculum are flexible. "One of our mantras is, we tailor all our courses to the customer's requirements." For example, if a group wanted to train engineers to fly experiments in space, that's what their course would focus on. For those who have less time, the material can be compressed, and the instructors also can teach the one-week academic module at a company's location.

Benefits

It was Oefelein's idea to start a spaceflight course at IFTI. "It's kind of hard to go get a degree in spaceflight," he says. "This gives you a lot of the practical knowledge you need to get into your job and be productive from day one."

A mechanical engineer graduating from MIT and hired by a spaceflight company likely knows little about space operations or space law, for example, says Glaser, noting that this represents a growing market as the commercial space industry continues to burgeon. "During the marketing we've done at trade shows, we have heard a lot of interest."

The astronauts' background not only informs the coursework but also lends credibility to the whole effort, Oefelein says. "I honestly don't think you can assemble this kind of team unless you have folks who have been there and done that." He refers to experience not only in space missions but also in engaging with the major players in spaceflight, from companies like Lockheed Martin to organizations like the Russian space agency Roscosmos.

In addition to his NASA background, Oefelein was part of the military space program, and both he and Glaser are veterans of the commercial space industry.

"Having been there is so key, especially with regulatory and political topics," Glaser agrees. "There's no other program where a professional can go and get that background from someone who has that experience."

"Commercial space now is where commercial aviation was 100 years ago," Oefelein says. "We want to tap into that excitement, the people who are excited and want to be part of building that."

While their customers may never need to improvise a spacewalk, IFTI hopes to use the lessons from such experiences to teach them the skills and knowledge needed to meet whatever unexpected challenges they will encounter while helping to push the boundaries of space travel. ❖

Polyimide Aerogels Boost Antennas, Insulate Pipes

NASA Technology

The challenge: make a powerful insulating material that is lightweight, strong, and flexible. The goal: an inflatable decelerator that can be folded up inside a spacecraft and then whipped out to create drag during landing. The bonus: a new material for warmer pipes, better antennas, and, potentially, gloves for astronauts on Mars.

Senior researcher Mary Ann Meador at Glenn Research Center knew where to start. The materials engineer had been working with silica aerogels: low-density solids filled with nano-size pores that make them superb insulators. They are created by dissolving a material in a solution to create a gel, almost like Jell-O. Then the solvent is dried out, leaving just the gel structure: a network interspersed with tiny pockets of air where the solvent used to be. The problem was that, made out of silica, aerogels are brittle, like glass.

"We were trying to build an inflatable structure contained in the rocket shroud for, say, a trip to Mars. When you get close to Mars, you would deploy this thing, like an umbrella in front of the spacecraft that would create drag," she explains. Historically, the blunt body shape of the aeroshell has been used to help slow spaceships as they pass through the atmosphere. But to send the heavier loads needed for human missions to Mars, or to slow down fast enough to land in some of the Red Planet's high-altitude locations, engineers needed something bigger.

At first, Meador's team had experimented with reinforcing the silica structure with polymers. That made the material better in some ways, she recalls, but it wouldn't be enough to work in an inflatable decelerator.

Instead, they decided to make an aerogel directly from the polymer. They chose polyimides for their strength and ability to withstand extremely high temperatures. After all, even as an interior insulation layer, the material had to be able to withstand temperatures of 1,100 °F for at least 90 seconds in order to ensure it wouldn't burn up during atmospheric entry.

Meador and her team succeeded at making aerogels out of polyimides and found them to be five times stronger than the polymer-reinforced silica aerogels when cast into a thick layer. However, making them thin enough to be truly foldable proved challenging.

"The first ones we made that were somewhat flexible were probably on the order of maybe a quarter-inch thick," Meador recalls. "I remember having a meeting with the program managers for the project, and, not appreciating what a major thing that was, they just kind of bent them and cracked them in half and said, well that's not very good."

"After that broke our hearts," she says with a laugh, "we went and started making them even thinner, casting them as films on the order of half a millimeter thick. At that point you could crease them and they could be unfolded and not crack." And if you used many thin layers, you could retain that ability to be folded, while still creating enough insulation for the heat shield.

Technology Transfer

In 2015, Spencer, Massachusetts-based FLEXcon licensed the technology after coming across the Glenn Research Center booth at a NASA Technology Days showcase, explains FLEXcon original equipment manufacturing director Ken Koldan. "Around that time, we started looking at other companies who create aerogels, and we ran across Blueshift. We made an investment in Blueshift, and from there, we got together and then approached NASA with the concept of: let's license the technology directly."

Blueshift was also working with polyimide aerogels, but its process did not achieve the same levels of thermal insulation as Meador's, Koldan says. After licensing the technology Glenn, FLEXcon, and Blueshift were able to work together to produce the material to NASA's higher specifications, on a much larger scale.

NASA reseracher Mary Ann Meador chose to make aerogel out of polyimides because these polymers are very strong and able to withstand extremely high temperatures. Making it in layers that were thin enough to be truly flexible was a challenge, but she and her team ultimately were able to cast layers just half a millimeter thick.

"We sell 100-foot rolls from two mils, or two-thousandths of an inch, (0.05 millimeters) up to 80 mils (two millimeters)," Koldan says.

Benefits

Polyimide aerogel has very low thermal conductivity with a very stable structure. The thin film format is sold to make protective wraps to insulate pipes in extreme environments, and FLEXcon is exploring markets for consumer goods as well, like a high-end jacket for outdoor athletes.

"Because it's an open-cell structure, it allows moisture to get out but then also has the ability to insulate," Koldan says. And the thin, flexible material means a less bulky product.

The material also works extremely well in antennas, because the highly porous structure offers very low resis-

tance for electromagnetic waves to pass through. "You wind up with a 70 percent lighter antenna due to the 0.15 gram-per-cubic-centermeter density and with 80 percent further range due to the dielectric constant of 1.2 for a given set of antenna performance parameters," Koldan says.

"From that standpoint, that's another reason FLEXcon got very excited about polyimide aerogels," he adds. "Think of all the places you could use this material; look at how many things involve electromagnetic radiation. Whether it is in the back bumper of an automobile which senses collision detection, all the way to planes that have radar in the nose tips, and wireless routers, they all have antennas in them." So far, FLEXcon has had interest from Government entities developing antennas with polyimide aerogels for military applications, and Koldan says he thinks private companies won't be far behind.

For insulation, as well, he says, "the market potential is pretty high. As things get smaller and faster, they generate more heat. And so being able to isolate heat and cold from things is always going to be important. And aerogels are a great way to do it."

The company is already seeing dividends from its investment in the NASA technology: Blueshift has hired five new people to handle the increased business requests thanks to this license agreement.

"The industry adopted the polyimide aerogel a lot more quickly than we thought they would," Koldan says, with sales starting about a year ahead of what FLEXcon projected.

The project Koldan says he is most excited about is with Brooklyn-based Final Frontier Design, which was awarded a NASA Small Business Innovation Research contract to design a next-generation spacesuit glove that could end up on astronauts heading to Mars. The skin-tight mechanical counter-pressure glove would reduce bulk as well as the dangerous risk of puncture in space, Final Frontier says.

The spacesuit glove was not something Koldan says he or his team ever considered as it studied the market potential of polyimide aerogels. "No one in the room thought of a glove that astronauts are going to wear on Mars. That was the most surprising one to us, the coolest."

For a company that has been evolving since it was founded by Myles McDonough in his garage some six decades ago, Koldan says, the new doors opened by the NASA partnership are very exciting. "To go from making material for a pair of women's shoes and now to material for a Mars glove—we've come a long way with technology." ❖

This artist's rendering shows an inflatable heat shield that is expanded to create drag during landing. To build it, NASA needed a lightweight, strong, and flexible material that was also an excellent insulator. Glenn researcher Mary Ann Meador created a polyimide aerogel that fit the bill.

Engineers examine an inflated heat shield after it was tested in a vacuum at NASA's Langley Research Center. These Hypersonic Inflatable Aerodynamic Decelerators, or HIADs, may prove more economical and efficient for carrying heavy loads to planets with an atmosphere.

Privately Built Facility Offers Advantages in Space Exposure Testing

NASA Technology

The conditions of space are, perhaps thankfully, difficult to reproduce on Earth. Most of the universe, beyond the atmospheres of its occasional planets, is an airless void full of dangerous radiation and other conditions that can harm not just organisms but also many materials. These conditions can be created in a laboratory, but imposing all of them at once is too difficult to be practical.

This is why, since 2001, NASA has carried out its Materials International Space Station Experiment (MISSE) series, bringing a variety of specimens into orbit to see what happens to them.

Objects in space experience extreme heat and cold, depending on their exposure to the sun. Solar radiation includes not just heat and light but also ultraviolet rays and charged particles. These can break molecular bonds but on Earth are largely blocked by the atmosphere and magnetosphere. And in low-Earth orbit, where most human space activity takes place, that ultraviolet light breaks apart stray oxygen molecules from the atmosphere to create atomic oxygen, which is highly reactive and tends to damage organic materials it interacts with.

During eight MISSE deployments, NASA has put thousands of specimens to the test, most being materials and components considered for use in space, although organic samples like seeds and spores have also been flown. Each mission included hundreds of samples in tiny containers, collected into larger containers that were housed on the outside of the International Space Station (ISS).

Future material science research on the ISS will be conducted on a new MISSE facility, where some of the space is reserved for NASA research, but the rest is available for use by companies, universities, and other Government agencies.

Technology Transfer

Either NASA or the Naval Research Laboratory has always managed the MISSE series, although a company called MEI Technologies (MEIT) has packaged the payloads and ensured they met constraints for weight, space, and other factors in support of the Department of Defense Space Test Program, which sponsored the payloads.

An astronaut installs a Materials International Space Station Experiment (MISSE) facility on the exterior of the ISS during a spacewalk in 2001. Future iterations of MISSE, handled by Alpha Space, will be installed and maintained via robotic arm, eliminating reliance on spacewalks.

The next deployment, set for mid-2017, will be different. It—and all future MISSE experiments—will be managed entirely by Alpha Space, a spinoff from MEIT located in Houston, which will not just integrate the payloads but build the containers and housing that hold them.

The transfer to a private company is part of a larger change taking place in the U.S.-owned portion of the ISS, known as the National Laboratory.

"It's not a shift in how the National Lab is run, it's a shift in how we're seeking to acquire new capabilities," says Mike Read, who manages the National Lab Office at Johnson Space Center, noting that NASA is now often seeking commercial partners to upgrade or add facilities on the ISS. "It's a totally different approach than the one we've traditionally taken," he says. "The budgets we had didn't support the traditional approach, so we began seeking opportunities to acquire services by buying them, rather than by buying hardware."

When NASA put out a call for a company to develop and operate MISSE, MEIT, well familiar with the program, responded and was subsequently chosen, creating Alpha Space to run as a commercial entity. Under cooperative agreements with Alpha Space, Johnson is helping to fund the new platform's development and covering some of the company's risk, while Alpha Space will rent out the portions of MISSE that don't belong to NASA.

The facility is scheduled to be delivered to NASA in March 2017 and flown to the ISS soon after, depending on launch schedules.

Benefits

Stephanie Murphy, principal owner and president of Alpha Space, says the "new and improved" testing facility, which the company designed, will present several advantages over previous iterations of MISSE while keeping costs to customers the same or lower.

For one thing, commercial customers can avoid the bureaucracy of obtaining NASA approval and sponsorship, she says. "You can come straight to us, so the time and expense it takes are both less."

This is a prototype of Alpha Space's MISSE facility. With containers facing in four directions and able to open and close independently, the facility can customize space exposure for different samples.

A major difference is that payloads will all be installed and removed by the station's external robotic arms, whereas previous units were all handled by astronauts during what are known as extravehicular activities (EVAs). "We don't have to wait for an EVA to be scheduled and risk falling off the bottom of the EVA agenda," says Johnnie Engelhardt, Alpha Space's MISSE build project manager, adding that this also helps keep the cost down. "EVAs are not cheap."

While earlier units faced one or two directions and were opened by astronauts when installed and closed upon their retirement, the new one will face four directions, with the carriers opening and closing independently. This allows samples to be exposed for different lengths of time and also allows the facility to protect its contents from contamination while vehicles maneuver nearby. Alpha Space will control all this from the ground.

By housing carriers in all four directions, the facility allows experiments to be exposed to different elements. For example, those facing the wake side, behind the space station, are not exposed to atomic oxygen, while those on the zenith side receive full exposure to the sun. This selectivity can help researchers determine which elements are causing degradation. Carriers can even be moved in flight if the ISS changes its angle.

The new facility will have more robust data connections than its predecessors, transmitting experiment health and status data once per second and supporting more experiments. "It's real-time monitoring, really," Murphy says. The data will come from sensors that monitor temperature, atomic oxygen, ultraviolet exposure, radiation, and other conditions, as well as contamination, although Engelhardt adds, "The sensor package can be anything the principle investigators want it to be."

The contamination sensor, a quartz crystal microbalance capable of picking up contaminants as small as an atom, is new, as is a high-resolution camera on a trolley in each of the 12 carriers. The camera will be scheduled to take pictures of each sample once a month so experimenters can have a time-lapsed history of a sample during its time in orbit.

Another factor that will keep costs down is that the facility will be permanent, whereas housings for previous missions were flown up with the experiments and discarded after retrieval. The new arrangement will reduce the size and mass, and therefore the cost, of sending up and returning MISSE payloads.

"When you have the infrastructure in place, it becomes a lot cheaper," Engelhardt says.

"We really have a plug-and-play model, and that's what makes it so much more affordable," Murphy adds. She says many of the changes in approach came from lessons MEIT learned from its years of managing payloads for these missions.

This, she says, is another advantage the company has. "Even though we're small and new, we have access to engineers with 20, 30 years of experience at a moment's notice," Murphy says. "That's the unique ace we have in our back pocket."

Alpha Space began officially lining up commercial customers in February 2016 for the facility's first flight.

Murphy says NASA's partnerships with businesses in low-Earth orbit are opening the space economy to companies that don't necessarily have a background in technology. "I think we're one of the first companies on the ISS who aren't engineers who saw an opportunity to advance their technology—we're entrepreneurs who saw a business opportunity," she says.

In addition to improving next-generation spacecraft, MISSE experiments have potential applications back home on Earth. Research on atomic oxygen exposure could lead to better fire-retardant and rust-resistant materials, and ultraviolet radiation research has the potential to improve structural materials like plastic siding for houses. Among the results of past MISSE missions is a static-dissipating paint that was used on the Curiosity Mars rover and will help protect communication, weather, and Earth-observing satellites. ❖

A prototype of Alpha Space's MISSE containers unfolds. Each will carry dozens of material samples, testing their reaction to prolonged exposure to the elements of space.

Optical Filters for NASA Imagers Focus on Cutting Edge

NASA Technology

By the time the Hubble Space Telescope launched, NASA engineers had already set their sights on its next upgrade. With camera and detector technologies improving at a rapid pace, service missions to replace many of the optical components were already scheduled.

Optical engineers at Goddard Space Flight Center needed specially designed filters for the Wide-Field Planetary Camera 2 (WFPC2) and, later, Wide Field Planetary Camera 3 (WFC3) to get high-quality images of stars, galaxies, and other celestial bodies from the Agency's flagship imager. Each of the filters had to block all but a specific range of wavelengths of light to capture the best scientific data possible.

Astronaut Andrew Feustel pushes off the Space Shuttle's remote manipulator system arm to deliver the Wide Field Camera 3 (WFC3) to the Hubble Space Telescope in 2009. Major process improvements that Barr Associates, now part of Materion Precision Optics, had to make to supply optical filters for the WFPC cameras and other NASA imagers led to improvements to the company's entire product line.

"In some cases, the requirements were for very, very narrow-band filters, because we wanted to look at some specific chemical constituent of stars that can be isolated in that narrow band of the light spectrum," explains Ray Boucarut, an optical engineer at Goddard who oversaw work on WFC3 . Our eyes are sensitive to light wavelengths between about 400 and 700 nanometers, but the cameras on Hubble and many other imaging telescopes look well beyond either end of the visible spectrum.

NASA also required filters on Hubble to be applied all the way to the outer edges of the optic—something that had not been attempted before—and to let in virtually every photon at the wavelengths they weren't made to block out.

"As you get into longer wavelengths or very short, the materials you can use become challenging," Boucarut says. "They won't function properly, they won't transmit the light very efficiently." The optics also had to be nearly defect-free, he adds. "The glass had to be polished to very high level to get the best wave-front optical quality."

Another challenge, particularly for WFC3, was that the filters for infrared imaging had to function at very low temperatures, around -20 to -40 °C, as warmer temperatures "would swamp your detector" and wash out any images, Boucarut says.

The mission to replace some of Hubble's original optics meant NASA needed to find a company capable of tackling all those challenges. Following a competitive process, Barr Associates, now part of Materion Precision Optics in Westford, Massachusetts, was selected.

Technology Transfer

The Hubble contracts presented new challenges for Barr Associates, a company with a long track record of providing precise, custom optical devices for aerospace applications and a range of other industries.

Materion Precision Optics developed a whole new lens-coating process to produce the unprecedented uniformity and wavelength positioning required for the James Webb Space Telescope's Near Infrared Camera, pictured here. It's a process the company now uses to create standard products on a daily basis.

For example, the company had never attempted to combine four filters on a single optic prior to the Hubble work, says David Harrison, a business development manager with Materion who worked at Barr Associates in the days of its Hubble work.

"We had done simple coatings on one substrate before but certainly had never taken anything to the precision level that NASA needed as far as spectral wavelength control, uniformity control, the precision of where each filter needed to be in relation to the substrate and in relation to each other," he says. "We took some known things in a few areas and put them all together to come up with something that really had never been done and was tighter than we could've imagined we could do."

> A lot of the lessons we learned from the Hubble work, back in the late '80s and early '90s, we still employ a lot of that today, certainly in improved processes and procedures."
>
> — David Harrison, Materion Precision Optics

At the time, the company showed great flexibility and willingness to work with NASA to create the filters, something Boucarut recalls with appreciation. On a few occasions, scientists from Goddard traveled to the company's headquarters in Massachusetts to talk about the work with engineers. "The scientists would discuss what led to the requirements we put on them," he says. "Sometimes we would negotiate something that would be easier to make but still satisfy the science. That flexibility on their part was a great benefit."

Boucarut also points out that the contract from NASA for the Hubble filters wasn't exceedingly large, roughly $2 million or less. The company's biggest business at the time was in telecommunications, but it had a small division of experts working on astronomy projects for NASA, universities, and other science-related entities.

In all, Barr Associates made nearly 100 filters for WFPC2 and WFC3 , but the relationship with NASA didn't end there. The company later provided filtered lenses for the Mast Camera on the Jet Propulsion Laboratory's Curiosity Rover and, now as part of Materion, has provided filters for the Near Infrared Camera on Goddard's James Webb Space Telescope, scheduled to launch as Hubble's successor in 2018.

Benefits

"A lot of the lessons we learned from the Hubble work, back in the late '80s and early '90s, we still employ a lot of that today, certainly in improved processes and procedures," Harrison says. In addition to its aerospace work, which includes filters for many of the world's major telescope programs, Materion applies these advances to high-end, precision optics for consumer goods, such as cell phones, laptops, tablets, and other electronics.

In one example of a major commercial success, the company took the technical know-how it developed to put multiple filters on a single Hubble optic and used it to create devices for matching paint colors in hardware stores. "It's the same idea, in that you now have multiple color coatings on one substrate, which allows a really small instrument to do evaluation of a number of different wavelengths," Harrison says, noting that Materion now sells thousands of the devices each year.

But advances made to meet NASA's needs have paid off across the board. Work on optics for the Curiosity Mars rover pushed the company's ability to eliminate even the slightest defects from its lenses, Harrison says, noting that Curiosity's lenses could not have imperfections larger than 1 or 2 microns, whereas most lenses can tolerate defects up to 100 or 200 microns.

"All of the protocols we've done to solve that one job are now followed in nearly every coating chamber we run nearly every single day now," he says.

Later, the company had to develop a whole new lens-coating process to supply optics for the James Webb Space Telescope. For that project NASA wanted unprecedented, "ridiculous" uniformity and wavelength positioning in filtering for mid- and long-wavelength light frequencies, Harrison says. While coatings to filter for mid-wavelength frequencies are usually applied through evaporation, those that filter for longer wavelengths are normally applied with an ion gun, he explains.

"Some of the properties they were asking for from their mid-wavelength coatings needed some of the extra energy from the ion-gun, but it wasn't something that was done up at that wavelength region," he says. With changes to deposition parameters, ion gun settings, and other points of process, Materion managed to come up with a successful recipe. "Literally, that one development chamber that we used for James Webb, there are now three of them that run standard products for us that way every day," Harrison says. "That was certainly a case where something NASA-related absolutely stretched our limits and capabilities and made us open our eyes to something completely different."

He says this is the biggest reason the company has always embraced NASA work. Meeting the Space Agency's demands for cutting-edge technology "pushes you to go beyond the safe zone, beyond what you can do and come up with ways to accomplish things you didn't know you could. It always keeps you pushing forward, striving forward, learning better ways to do stuff, which helps the company in so many ways overall," Harrison says.

"As we solve new problems, it makes us think of new ways and things that are outside the box that cascade down into our everyday commercial-type optics." ❖

The technical challenges that Barr Associates, now part of Materion Precision Optics, had to overcome to put four filters on a single optical element to meet the requirements for Hubble Space Telescope imagers later led to paint-matching devices for hardware stores, with multiple wavelengths evaluated by a single lens. This is just one example of improvements and innovations the company made to meet NASA's needs that then made their way into commercial products.

Zinc-Silicate Coating Blocks Corrosion

NASA Technology

NASA needs materials that are strong and can hold up over time. Sometimes that means the Space Agency designs brand-new, high-tech materials—but sometimes it sticks to industry standards, like steel, and creates a game-changing coating to protect it from the elements.

The good news is that anyone else using that tried and true material can benefit from the new coating too.

That's just what happened in the 1970s, when a team at Goddard Space Flight Center developed a mixture of zinc powder and potassium-silicate to protect metal surfaces from corrosion.

Zinc had long been used in anti-corrosion coatings, but NASA wanted something that was easier and more cost-effective, so Goddard chemist John Schutt began to play around with the formula. The product he ended up with did more than cover the metal to block sea spray, fog, or other corrosive elements. It actually chemically bonded with the underlying material.

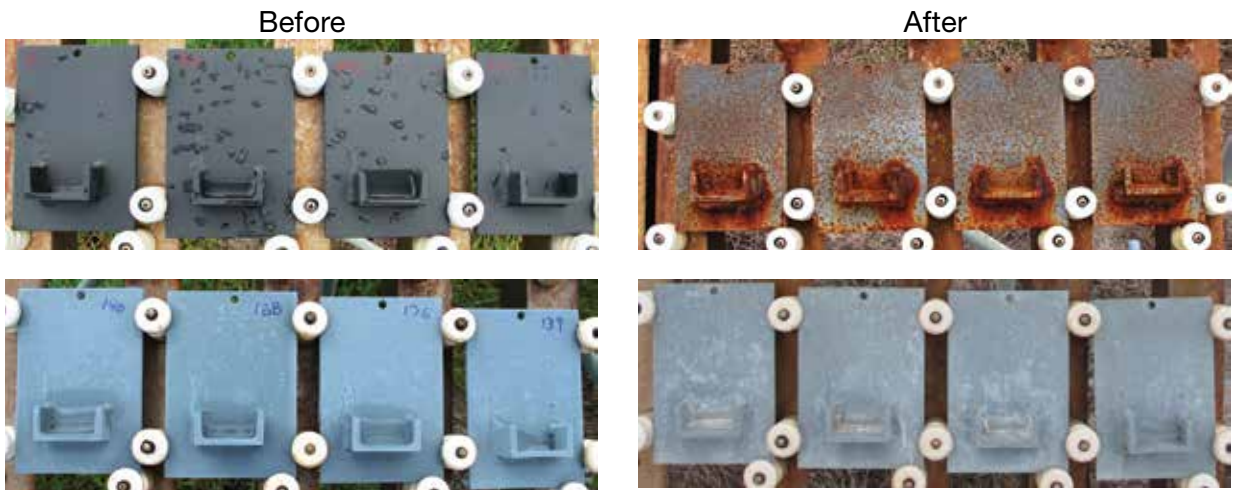
In other words, explains Earl Ramlow, who started using the coating more than 20 years ago as an engineer working for a military contractor, once you apply the coating, "it becomes part of the parent steel."

The result was an incredibly effective and durable treatment that didn't even allow water damage or corrosion to seep into protected areas if the coating was scratched or incomplete.

NASA put the coating to use on structures at the seaside Kennedy Space Center, where it protects launch facilities not just from the salty, tropical environment but also from the temperature spikes and high-heat exhaust of rocket launches.

Technology Transfer

But the Space Agency wasn't the only organization with structures to protect. The coating was soon put to use on a range of metal structures, from bridges to boats to the Statue of Liberty.



In a recent test at Kennedy Space Center, engineers applied environmentally friendly coatings to steel samples. After 18 months' exposure in the salty sea air, the Polyset coated samples, bottom, remained nearly pristine, while the ones coated with another product, top, became riddled with rust and corrosion.

To sell the coating in the private sector, NASA had licensed its patent to a company called Inorganic Coatings (*Spinoff* 1984, 1985, and 1990).

But, explains Ramlow, before the company could produce the coating commercially, it had to perfect the manufacturing of one of the key ingredients, liquid potassium-silicate.

"NASA basically had the recipe on the proverbial napkin," he says. "Even the patents describe the raw materials with very basic instructions."

Inorganic Coatings turned for help to another company, Polyset, founded by two former GE chemical engineers. "So they sat down in the basement and tweaked the processing" until they consistently got good results, explains Ramlow. Polyset, based in Mechanicville, New York, then signed an agreement with Inorganic Coatings to provide them the liquid silicate exclusively for the NASA-derived coating.

But when Inorganic Coatings later tried to produce the silicate itself to save on costs, it was unsuccessful, and the faulty product it produced helped put the company out of business.

Ramlow experienced the problem firsthand in around 1989 or 1990, when he was working for a military contractor assigned to build causeways for the U.S. Navy, with Inorganic Coatings supplying the anti-corrosion coating. "Because Inorganic Coatings didn't manufacture the silicate properly, when we applied the coating, it would look good, but as soon as we would put the causeway modules outside in dew or rain, it turned back into a liquid," Ramlow says.

Later, other companies began making the coating, using liquid silicate manufactured by Polyset. But then history repeated itself, and once again Ramlow was stuck with a faulty product.

In 2002, he was working on another project, building modular causeway systems for the U.S. Army. But the anti-corrosion coating that was delivered didn't use the Polyset-made liquid silicate.

"It was déjà vu all over again. The coating was resolubolizing, turning back to liquid," Ramlow says.

Although Ramlow was able to finish both projects successfully—ultimately by sourcing the coating to one made with Polyset's liquid silicate—the 'black eyes' from incorrectly manufactured batches and advances in other coating technology saw the product start to fall out of use.

But the NASA formula, when manufactured correctly, is still the best product available to prevent corrosion of metals, Ramlow says, and Polyset was the one company that had the ability to produce the key ingredient consistently.

So in 2010, Polyset decided to take the coating directly to market under its own brand name: WB HRZS Single Coat System, where the acronym stands for water-based high-ratio zinc silicate. It created a new protective coatings division and, because of Ramlow's history with the product, hired him to head it.

"This is a technology that was almost lost by the industry because of its history. It was buried. It was forgotten. Polyset has brought it back to life," Ramlow says.

Benefits

One of Polyset's first customers for the coating was Chevron Oil, which is using it to protect its offshore oil rigs.

Ramlow described the benefits to the company, saying a single coat will prevent problems even in the splash zone, which is highly susceptible to corrosion. The Chevron representative was skeptical, he recalls, but agreed to test a small patch on a rig in the Gulf of Mexico.

"He told me, 'I'll call you in a month or two, because it's going to fail,'" Ramlow recounts. But 12 months later, he called with different news: the test area had remained pristine, even though the rest of the metal was corroding all around it.

"That's a key benefit of this coating: if you've got an area of unprotected steel, or the coating is damaged somehow, it will never undercut or blister in the protected area, because the coating is chemically bonded to the steel."

That chemical bond also adds another benefit: it allows the surface to be electrically conductive, which deters marine critters, like barnacles and mussels, from clinging to the surface, Ramlow says.

Another benefit is that, unlike many other inorganic coatings that must be applied in a single pass or sandblasted off to try again, WB HRZS can bond to itself, so if the first coat is not thick enough, it is simple to go back and fix. And although just a thin coat—Ramlow recommends six- to eight-thousandths of an inch—is required, there is no harm, he says, if some spots end up thicker, unlike with other inorganic zinc coatings that crack when over-applied.

And because it is water-based, it's a lot safer and more environmentally friendly than coatings that include solvents or thinning agents.

In fact, in a recent study at Kennedy of 21 coatings aimed at identifying environmentally friendly ones that meet NASA's requirements for launch facilities, the Polyset product was one of just four to pass, says Kurt Kessel, who oversaw the testing. "It made it through all of the testing and it made it to the initial qualified products list," he says. "It's been initially accepted under the NASA specifications."

Not a surprise, perhaps, considering the source of the formula, but Kessel said the testing was necessary since Polyset is a new manufacturer as far as NASA is concerned.

The company is working on expanding its customer base among companies that make ships' hulls and interiors, as well as rail cars, hydroelectric plants, and bridges, and it is also going through the process to become an approved supplier for the departments of defense and transportation.

"Every year since 2010 we have doubled our revenues," Ramlow says of Polyset's coatings division, adding that when he makes his marketing pitch, he always invokes the NASA name, especially when he sees doubt about the performance of the coating. "I always tell people, remember where this product was born: NASA, a collection of the smartest engineers and scientists in the world, who work on spaceflight programs, where lives are at stake." ❖

Polyset sells its coating to companies that operate offshore oil rigs like this one, which can suffer corrosion from the seawater. The company is also targeting ship and train builders, hydroelectric plants, and the departments of defense and transportation.

Outgassing Test Facility Brings New Materials into Space Industry

NASA Technology

Anyone who can remember when cars had vinyl dashboards may be familiar with the hazy film that could appear on the windows during a hot, sunny day. This was the result of offgassing: volatile compounds in the vinyl, excited by the trapped heat, escaped into the air and condensed on cooler surfaces. Similar to offgassing, outgassing occurs when certain materials are subjected to the vacuum of space. Outgassing can pose a significant problem to spacecraft engineers, as their creations will be subjected to extreme temperature fluctuations due to the sun's unfiltered radiation. If a film forms on surfaces, there won't be anyone around to wipe them down.

The problem is only exacerbated by the fact that a craft's colder surfaces include crucial components such as lenses, mirrors, and windows. "If a substance gets heated up and gives off condensable volatiles, in a vacuum, they're going to be drawn right onto cold surfaces," says Debbie Thomas, a senior materials engineer with Ball Aerospace, who has run the Outgassing Laboratory as a contractor at NASA's Goddard Space Flight Center for the last 15 years.

For almost half a century, the lab has been building a database on the performance of materials and components—more than 11,000 of them and counting. In addition to testing materials for NASA's projects, until a couple of years ago, the lab also offered testing to outside entities as space and schedules allowed. The service helped companies prove their products' spaceworthiness, and it also augmented the Agency's database, which is now online and used as a reference not just by NASA but by engineers all over the world.

Feedback from users around the world indicate the widespread use of the database. Thomas says she has received emails from Taiwan, Europe, and elsewhere. "A lot of people use it every day."

Among the last specimens she tested for a commercial entity were four variations of CRP USA's Windform 3D printing materials. The tests marked the beginning of applications in a whole new industry for a family of materials that had been finding new applications since they first started out in the Formula 1 racing industry.

Technology Transfer

CRP USA, headquartered in Mooresville, North Carolina, is part of the Italian-based CRP Group, which invented the first Windform materials in the early 2000s. These are polyimides reinforced with carbon or glass microfibers. They vary in properties like electrical conductance, water resistance, static dissipation, and elasticity but are generally valued for providing high strength at low weights.

Another key advantage: Windform materials can be used in 3D printers that employ selective laser sintering. The process can print almost any shape as one solid object, create multiple objects simultaneously, and ensure the absence of voids in the material that can occur with other additive manufacturing processes.

CRP first used the material to build Formula 1 models for testing in wind tunnels, but soon they were using it to create end-use parts of the racecars themselves and then pieces of racing motorcycles, before moving into the boating, architecture, defense, medical, and entertainment industries.

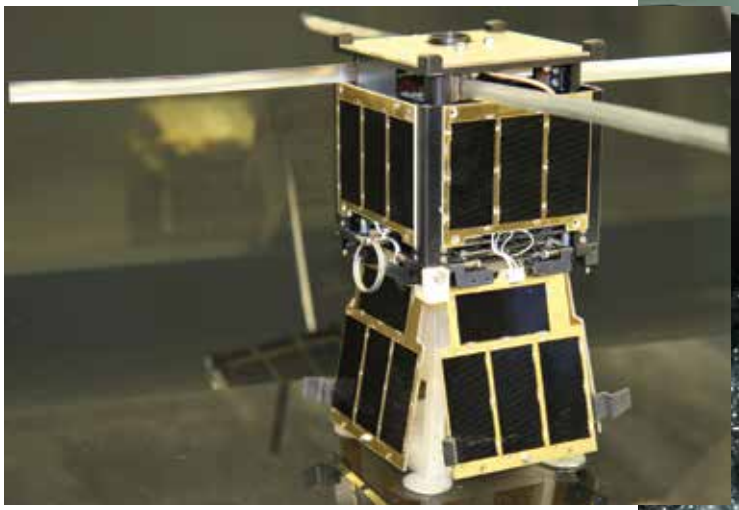
Even so, Stewart Davis, CRP USA's director of operations, wasn't aware of outgassing tests until an acquaintance contacted him about the possibility of using Windform on a satellite and asked whether the materials had been tested for volatile compounds. "If you haven't had that test, they won't let you fly it," Davis says.

A friend at Northrup Grumman managed to get one material, Windform XT, tested. "We didn't think it would pass, but we said, we'll give it a shot," says Davis. It did pass, and the company's interest was piqued. That was when he heard Goddard offered the testing.

Goddard's Outgassing Laboratory tests materials by placing them in 50 percent humidity for 24 hours, followed by 24 hours in a vacuum at 125 °C, or nearly 260 °F. Any condensable volatile compounds will flow through a hole in the chamber to a collector plate held at 25 °C. The material is then weighed to determine the total mass lost due to heating in the vacuum, and the plates are weighed to determine the collected volatile condensable material. The samples are then placed back in 50 percent humidity for 24 hours and reweighed to confirm how much of the lost mass represented water weight.

It's a technique Stanford Research Institute developed in the mid-1960s under contract to NASA's Jet Propulsion

Montana State University's PrintSat satellite's housing (left) is made with 3D-printed Windform material, as is a hybrid rocket engine built by Experimental Propulsion Lab (right).



Students at the University of Kentucky and Morehead State University used 3D-printed Windform material to build their KySat-2 CubeSat, a proof-of-concept spacecraft to demonstrate technologies the students developed.

Engineers at Goddard Space Flight Center use carbon dioxide "snow" to clean a test mirror for the James Webb Space Telescope. Because they're cold, components like mirrors and lenses, which have to be completely clean and flawless in space imagers, are among the first places any volatile compounds outgassed from a spacecraft's materials will condense, causing fogging. To prevent this, all materials used in spacecraft have to demonstrate extremely low outgassing.

Laboratory, which was later adopted by the American Society for Testing and Materials as a standard test method.

Three samples are tested, and the results are averaged. To pass, a material's average total mass loss coming out of the vacuum must be less than 1 percent, and the condensable volatile material outgassed cannot exceed 0.1 percent. NASA's materials engineers use the results of the test as an initial screening test to determine the risk of contamination from outgassing.

CRP's materials all had total mass losses of around 0.5 percent and, more importantly, only 0.06 percent or less of their masses were outgassed as condensable volatile materials. In fact, two of them—LX 2.0 and XT 2.0—lost nothing but water.

Benefits

"A private company testing it and submitting results wouldn't have the same weight as the guys who put payloads up in space," Davis says, adding that the testing was "extremely useful, because anyone who checks that website knows the full results."

Since they were performed in 2013, the tests have led to business with 10 to 15 companies for whom CRP USA has produced components for use in space as well as supporting roles, such as prototypes or tooling devices, he says. "We had no space exposure before, and it's completely new and untried territory."

One of those partners is Millennium Space Systems, to whom CRP provides parts for small satellites under Millennium's Bootstrap program, aimed at building and launching affordable satellite systems with quick turnaround times. The company uses Windform XT 2.0 on the outside of satellites because of its electrical conductivity, which dissipates static charges, and its ability to deflect heat. Windform LX 2.0 is used to make internal components due to its lack of conductivity and similarly high heat resistance.

Their high strength-to-mass ratio also makes both materials, and especially XT 2.0, desirable for space applications, where weight is a major factor in launch costs, Davis says. "Our LX 2.0 and XT 2.0 are some of the lightest, strongest substances you can get for manufacturing with 3D printing."

Another advantage over metal for space applications is that Windform would burn up on atmospheric reentry, eliminating any concerns about debris falling to Earth.

Windform materials have also been used in a number of satellites built by students, such as Stanford University's Stanford Nano Picture Satellite, the KySat-2 CubeSat built by students at the University of Kentucky and Morehead State University, and Montana State University's PrintSat, although that one was lost to a failed rocket launch.

These early forays into the space industry have also led the company to work with the European Space Agency and the Japan Aerospace Exploration Agency, although they each ran their own outgassing tests.

"It's been interesting for us to learn about these different test requirements," Davis says, noting that the company has since learned that the testing could also make Windform preferable for some Earth applications where outgassing is an issue, such as camera housings and optical scopes. ❖

Shuttle, Hubble Work Lead to Strength in Custom Current Sensors

NASA Technology

When it was built, the Space Shuttle boasted the world's most complex avionics system. The Shuttle's controls were entirely digital, with all connections routed through wires and computers in what was known as a "fly-by-wire" system. All of the computer subsystems, which pervaded the spacecraft, were integrated. This allowed them to communicate with each other and automatically control functions like flight stabilization or engine performance.

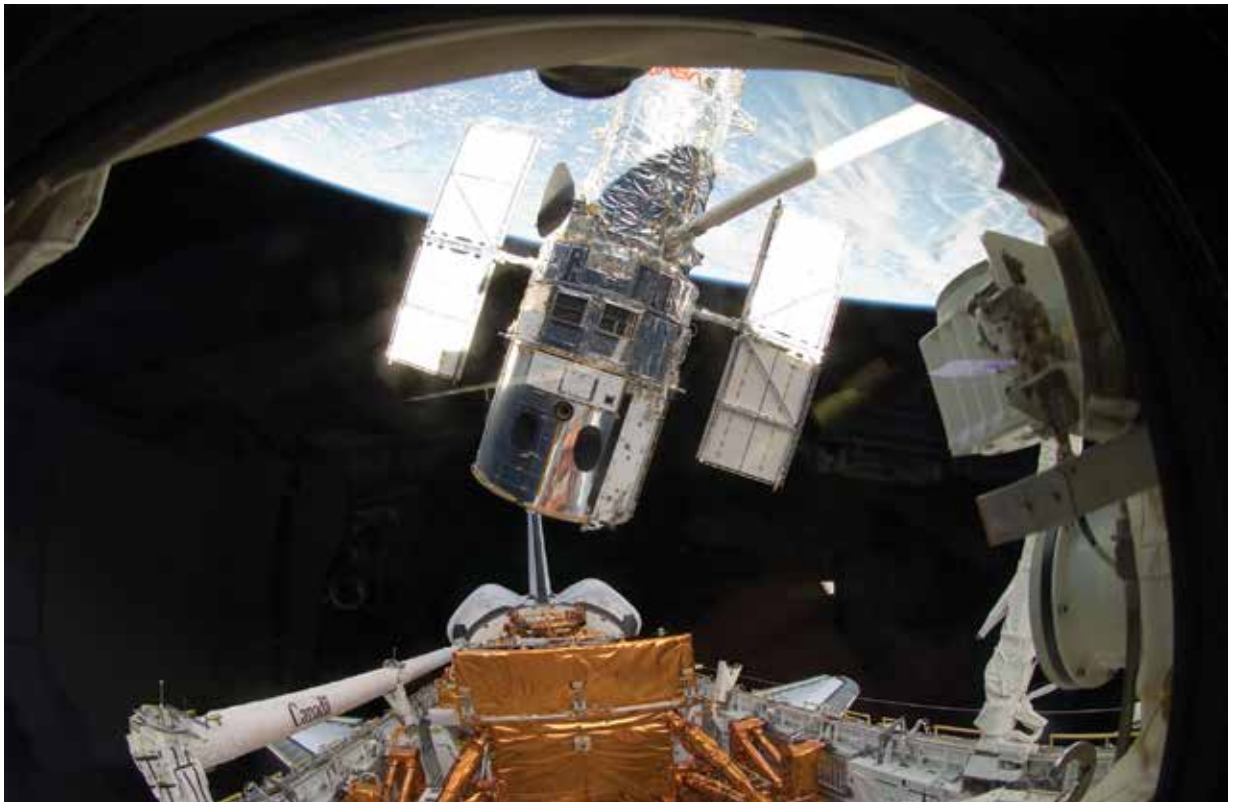
With all of the Shuttle's critical functions relying on them, the electrical systems had to be fail-safe, so they were redundant and closely monitored.

Meanwhile, the Hubble Space Telescope, like other satellites, relies entirely on energy gathered by its solar panels and stored in batteries to run its instruments, computers, and transmitters. During each orbit, it has 61 minutes of sunlight to store at least enough energy to operate throughout the entire 97-minute circuit.

With limited resources, power management is crucial to any space vehicle. Due to the cost per pound of escaping Earth's gravity, the electrical systems, like everything else on a spacecraft, are optimized to the limit, so changes in any component's performance can negatively affect overall operations.

Monitoring power flows on both of these iconic spacecraft were—and in the case of Hubble, still are—current sensors supplied by American Aerospace Controls (AAC), based in Farmingdale, New York. The various wires of the Shuttle's fly-by-wire system and Hubble's solar-powered organs were run through little current and voltage sensors the company provided as a subcontractor to Rockwell International for the Shuttle and Lockheed Corporation, now Lockheed Martin, for the space telescope.

Current sensing is more often accomplished with a shunt resistor connected to the circuit, which siphons energy while measuring its flow. For spacecraft that need to operate at maximum efficiency, however, AAC's noninvasive sensors, based on a coil that surrounds a wire without making contact with it, are preferable.



The remote manipulator system on the Space Shuttle Atlantis lifts the Hubble Space Telescope from the cargo bay during the final mission to service Hubble in 2009. American Aerospace Controls' first parts in space were current sensors in the Shuttle's avionics system, and the company's sensors are still orbiting Earth on Hubble.

Technology Transfer

The company, which specializes in current sensors, had provided some off-the-shelf equipment for NASA laboratories in the 1960s, but the custom Shuttle work of the following decades, coming out of Johnson Space Center, led to AAC's first products in space.

"The first time we were approached about space applications, it was something we had to stretch our capabilities to do," says Kevin McBrien, the company's vice president of sales and marketing.

As more Shuttle work, and then Hubble projects for Marshall Space Flight Center, rolled in, the company built up its ability to meet NASA's needs.

"Probably one of the first, biggest changes that came from working with the Shuttle was a real, live quality-control system," says Bob Baumert, vice president of engineering. "With spacecraft applications, they're usually buying a unique part that's tailored or application-specific." So the company might make only two or three of a certain

> It's a spinoff of capabilities and documentation that has allowed us to leverage the NASA work beyond NASA and abroad."
>
> — Kevin McBrien, American Aerospace Controls

design, but they would have to meet 40 or 50 requirements, particularly for the ability to endure intense vibrations, extreme temperatures, and radiation while resisting electromagnetic interference, he says. Parts also have to be small, lightweight, and highly efficient. Like everything else on the Space Shuttle, they also had to include the precautions of redundant functions and a back-up mode.

While most companies hire a subcontractor for product testing, adding to the time and cost of production, to meet NASA's high quality-control and quick turnaround requirements, AAC brought all this testing equipment and personnel in-house, says Piotr Pacholski, principal engineer.

The testing also required thorough documentation. "You have to prove on paper and by testing that your design approach is the right approach," Baumert says. So more engineers were brought onboard to handle the required paperwork.

The ability to produce, test, and document highly reliable, rugged, efficient current sensors won AAC contracts to provide 34 sensors for Hubble—which are still working more than 25 years later—and went on to secure the company a broad customer base in the private sector and overseas.

"It's a spinoff of capabilities and documentation that has allowed us to leverage the NASA work beyond NASA and abroad," McBrien says.

Benefits

While AAC started out making primarily standardized parts, with the NASA work, that focus shifted to customized sensors, primarily for aerospace applications. "We have sort of become the high-reliability, custom current-sensor manufacturer," says McBrien, although he adds that specialized work often has enlarged the company's catalog. "If we had 45 part numbers when we started dealing with NASA, today that number is in the thousands."

The Space Agency remains a customer, and AAC sensors are commonly used on satellites flown by the Department of Defense and others. The European Space Agency's contractors are frequent customers, particularly the Société Anonyme Belge de Constructions Aéronautiques, a major Belgian aeronautics and space company that also supplies businesses like Airbus, Dassault Aviation, Gulfstream, and Arianespace.

But AAC has found customers across the aircraft, rail, industrial, and defense markets as well. "As long as you need to use a sensor to see what's going on with a particular wire or power supply, you'd use us," McBrien says.

On a plane, the sensors might tell the pilot whether systems like the windscreen heating are on. McBrien notes that the company's in-house testing and documentation capabilities are used for anything that requires approval from the Federal Aviation Administration.

The ruggedness developed to stand up to the vibrations of liftoff and other harsh conditions has attracted customers from helicopter companies to the mining industry.

AAC recently was awarded its fifth Boeing Supplier Excellence Award. "None of that would have happened if we hadn't done our work with NASA from the start," Baumert says, pointing out that the company wouldn't otherwise be able to meet Boeing's standards. "Without question, in our company's 50 years, probably the single biggest thing that helped us grow was our initial work with NASA." ❖

The larger silver-colored unit is a current sensor American Aerospace Controls supplied for the Hubble Space Telescope and similar programs, while the smaller one is a more recent sensor the company supplies for satellite launch vehicles. Both are space-qualified, radiation hardened, and hermetically sealed to eliminate electromagnetic interference. The two black current sensors are used on NASA's RQ-4 Global Hawk and the U.S. Navy's MQ-8 Fire Scout, where they monitor the unmanned aerial vehicles' main electrical distribution systems. The company based them on designs originally created for the Shuttle program.

High-Heat Cement Gives Ashes New Life

NASA Technology

When constructing high-performance structures, at NASA or elsewhere, materials made from recycled ingredients might not seem like a good fit. But when it comes to concrete made from ashes, the environmentally friendly material may actually be better than its more traditional, nonrecycled counterparts.

One structure at NASA that takes more punishment than almost any other is the trench that deflects the inferno of flames and exhaust during a rocket test. The trench needs to be lined with a material that can take the extreme heat—thousands of degrees Fahrenheit, though temperature probes have struggled to get accurate measurements, because they burn up during testing, says aerospace engineer Nick Cenci.

The lining also needs to be able to resist wear and abrasion as much as possible. Typically, Cenci says, "as a material gets hotter, it gets a little softer and then it wears away faster."

Recently, Stennis Space Center, where Cenci works, tested geopolymer concrete—made with fly ash, the waste left over from burning coal at power plants—to see if it would be a good candidate to replace the current material that is lining these test stand flame deflectors.

"What we're after is reducing the erosion rate," explains Stennis engineer Daniel Allgood. "It's very, very costly for us to go in and cut out these sections that are damaged and repair it with new material. The less material that gets eroded, the better."

A team at Louisiana Tech University had been working with geopolymer concrete since 2006, exploring different formulations and applications. Unlike traditional concrete, in which cement, typically composed of limestone and clay, is mixed in a water-based solution with sand and gravel aggregates, the geopolymer concrete is mixed with an alkali solution and aggregates.

By choosing different alkali activators and different materials for the aggregates, as well as by changing the fly ash source, the Louisiana Tech team found they could fine-tune the properties of the finished concrete—achieving concrete that was stronger and more temperature- and erosion-resistant than traditional high-heat materials.

Rocket testing, however, would be a new frontier for the material.

Technology Transfer

At Stennis' E1-Cell 3 test facility, full-size rocket engines are bolted upright into the test stand. Fuel is piped in, and the rocket engines fire, letting out a massive plume of orange and yellow flames.

In 2012, Stennis used the E1-Cell 3 test stand to put an Aerojet Rocketdyne AJ26 rocket engine through its paces for Orbital Sciences, now known as Orbital ATK. The engine, which Orbital planned to use to power the Antares rocket to the International Space Station, "has a certain orbit it has to achieve, so it is designed to run at different power levels for different durations to get there," Allgood says. "For this engine, the burn lasted about a minute."

The flame trench is designed to withstand the test, but some wear and tear is par for the course. The AJ26 engine could be fired three times before making major repairs to the trench, but in between, engineers recoated patches as needed, explains Cenci.

And that's how Stennis tested the geopolymer concrete.

Earlier that year, Louisiana Tech had entered into a Dual Use Technology Development cooperative agreement with Stennis for the testing. Louisiana Tech supplied the materials—several new formulations of the geopolymer

The AJ26 rocket engine was flight tested at Stennis Space Center in 2012. That plume of flame wears away at the trench under the test stand, so Stennis teamed up with a team from Louisiana Tech to explore using a new kind of concrete, made with fly ash, to line the trench.

After the successful Stennis tests, the Louisiana Tech team founded Alchemy Geopolymer Solutions, leveraging their expertise in designing concrete made with fly ash. A pipe-maker in Texas was interested because of the material's high resistance to corrosion and its impressive compression strength.

concrete designed to NASA-specified parameters—while Stennis supplied the facility and people to carry out the trials.

An earlier round of testing, on a sub-scale test facility, had good results, Allgood says. "They gained understanding about the material, and we did as well." And at that scale, the material outperformed all but one of the commercially available high-temperature materials Stennis used.

Allgood and Cenci, who oversaw the testing for Stennis, decided to use the material for small patches on the full-size test stand, specifically E1-Cell 3, and see how it performed during a real-life rocket trial.

Both say they were impressed with what they saw, though further testing would be necessary before they would consider adopting the material as standard for the flame trenches.

Nevertheless, buoyed by the NASA results, which confirmed what they had been seeing in the lab, the Louisiana Tech team decided to start a company, Alchemy Geopolymer Solutions.

Benefits

Initially, the plan was to manufacture products similar to the formulations NASA tested, using Louisiana-sourced fly ash, and ship it to customers or help them install it, says Carlos Montes, one of the original Louisiana Tech researchers and now Chief Technology Officer at Alchemy Geopolymer Solutions LLC.

> "[Clients] think, 'Oh, they designed this for NASA, so they're probably good at designing materials for us too.'"
>
> — Carlos Montes, Alchemy Geopolymer Solutions

But the Ruston, Louisiana-based company soon found that their biggest asset was their expertise in devising new materials using fly ash—the same expertise that drew NASA's interest and which was further honed during the Stennis partnership.

"Most of our clients were not in Louisiana at all," Montes explains. "They wanted us to design geopolymer products with their waste stream, with their raw materials."

Fly ash is not particularly hazardous to the environment by itself, but it is a waste product that would otherwise be sent to a landfill. Additionally, using waste ash replaces the need to manufacture traditional limestone cement, a process that produces greenhouse gasses and consumes energy. And unlike many ingredients for high-performance cements, fly ash is relatively inexpensive.

For some of Alchemy Geopolymer Solutions' clients, these environmental and cost benefits are the main draw.

For instance, a company in Utah makes its profit from harvesting metals from incinerated garbage. The resulting ash was typically sent to a landfill.

"If we come in and make products out of the ash, they don't have to throw it away. And that creates another revenue stream," Montes says. For that client, they were able design a manufacturing process to make pavers and similar products, and they expected the company to take them commercial in early 2017.

Other clients, however, are drawn in by the high-performance properties of the geopolymer concrete, and the environmental benefits are a bonus, or even completely incidental.

A client in Texas already had a factory to build pipes, but they wanted to make them from geopolymer concrete because of its impressive anti-corrosion properties and compression strength. They specified the characteristics they needed in the pipes and the manufacturing conditions of their factory, and asked Alchemy Geopolymer Solutions to provide a process to produce pipes with geopolymer concrete, ideally using their local sources of fly ash.

"It took us about four or five months. Now they're doing field testing to install these pipes to monitor them for a year and get real data before they start commercializing their product," Montes says.

Another company, which runs coal power plants, is exploring using its own fly ash to make concrete to line the floors of its boilers. These, like the NASA flame trenches, suffer extremely high temperatures and corrosion from molten slag.

In its first two years of operation, Alchemy Geopolymer amassed a diverse client base and won a prestigious Startup Louisiana prize, which brought them funding and a great deal of positive press.

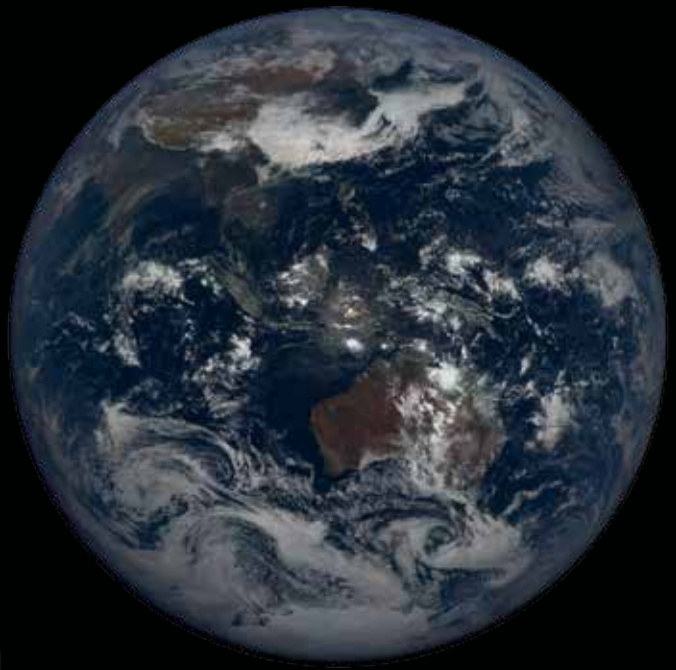
Montes says the NASA testing was a crucial stepping stone, giving them the confidence to start their company sooner and attracting clients for the new startup.

"This is definitely a very strong case study for us. Maybe not directly because people are trying to buy what NASA uses, but they'll think, 'Oh, they designed this for NASA, so they're probably good at designing materials for us too.'" ❖

Partnership News

Spinoff products aren't the only ways NASA benefits life on Earth. Each year, the Space Agency partners with numerous government organizations, educational and nonprofit institutions, and private businesses to conduct research, develop new technologies, and engage the public. These partnerships range from studies monitoring air quality or coral reef health to building the next generation of aircraft and pioneering a new kind of heart pump.





Partnership News

Deep Mind Learning

Scientists at Ames Research Center and the Mayo Clinic have developed the first implantable sensor for monitoring neurochemicals in the brain in real time, something that could one day help monitor astronauts' bone, muscle, and heart health on long space missions—as well as help treat Parkinson's disease on Earth.

The sensor, made of a carbon nanofiber nanoelectrode array, looks like a tiny, incredibly thin needle: it is roughly five millimeters long, less than half a millimeter wide and thinner than the diameter of a human hair.

Once it is implanted in the brain, the sensor is able to monitor the neurochemical response to deep brain stimulation. This could help doctors use the technique more efficiently, as they get real-time information on how much of neurochemicals like dopamine, serotonin, and oxygen and common interferents such as ascorbic acid are released during stimulation.

The scientists say their long-term goal is to help build a closed-loop "smart" deep brain stimulation device that incorporates ultrasensitive neurochemical detection and feedback control to improve clinical efficacy of deep brain stimulation therapy.

Full of Heart

Dr. Mark Rodefeld has spent decades fixing children's hearts, but one particular heart problem has consumed much of his research.

"About 1,500 children are born every year with a missing ventricle," said the pediatric heart surgeon at Indiana University. "It's actually the fifth most common problem in those with heart issues."

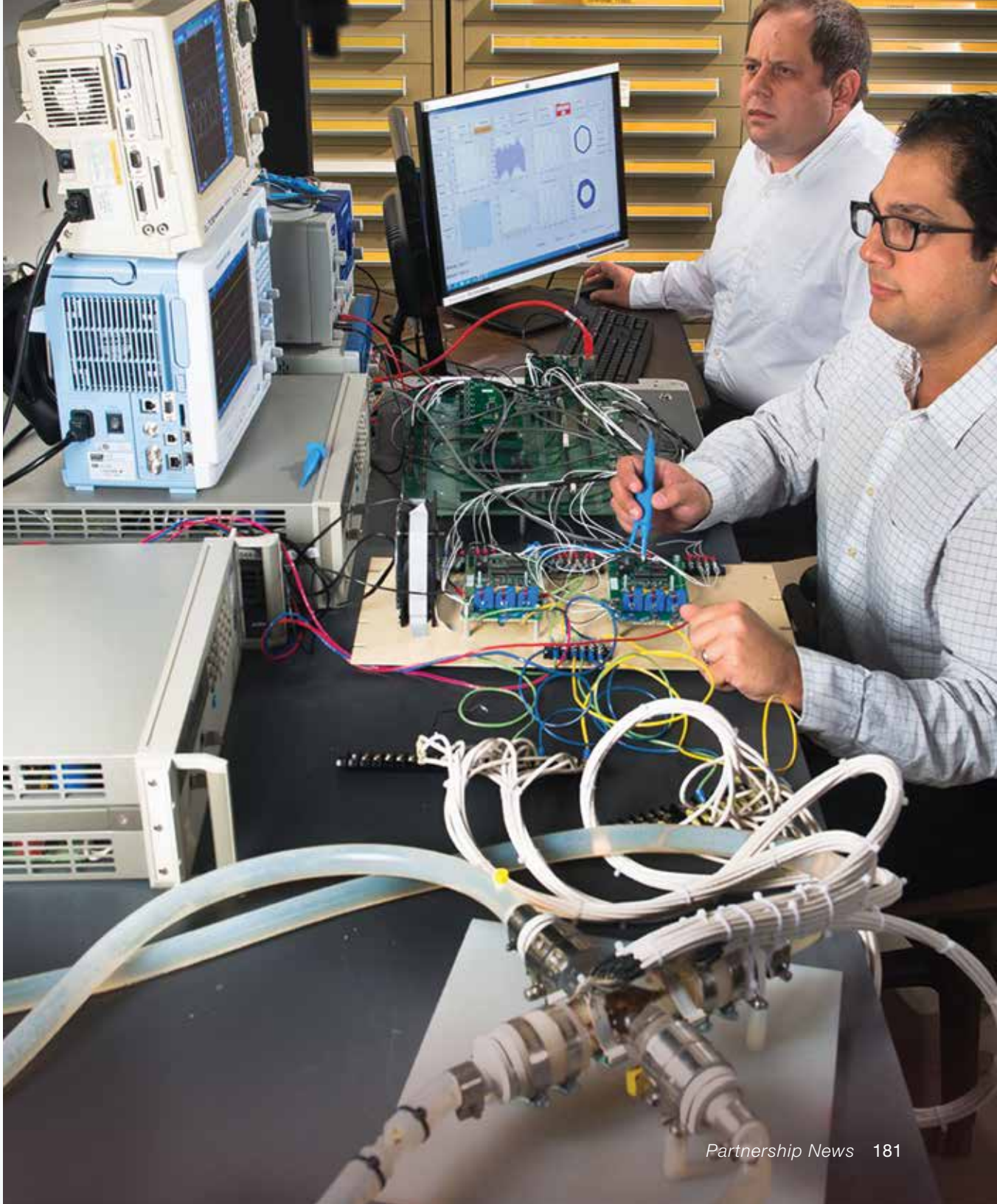
Patients commonly get a partial fix called the Fontan procedure to create a passive circulation network to replace the blood-pumping function of the missing ventricle, but pumping pressure is too low to work long-term.

Rodefeld came up with an idea to insert a small conical pump, driven by an electrical motor, into an existing Fontan network, but "I needed experts in flywheel technology at Glenn to design and scale it to size," he explains.

A team of engineers at Glenn Research Center spent two years designing, building, and testing a bi-conical heart pump for Rodefeld. Eventually they completed a functional prototype.

The Glenn team's extensive design, build, and testing led to successful results proving the feasibility of Rodefeld's original idea. Further development would help scale the motor down to the required diameter—the size of a nickel.

Over the next few years Rodefeld hopes to engage Glenn engineers in additional development and testing with the goal of advancing this life-saving technology for young patients.



NASA Glenn engineers David Avanesian and Peter Kascak test a flywheel motor designed for a heart pump to help circulate blood for children born with only one heart ventricle.

On Thin Ice

Operation IceBridge, NASA's airborne survey of polar ice, completed its eighth spring Arctic campaign in 2016, adding to a trove of data on changes in the elevation of the ice sheet and its internal structure.

IceBridge's readings of the thickness of sea ice and its snow cover have helped scientists improve forecasts for the summer melt season and have enhanced the understanding of variations in ice thickness distribution from year to year.

"Our main priority is to look at the changes that have taken place since our previous campaigns, especially to look at fast-retreating glaciers like Jakobshavn and see how far inland they're melting away," said Eric Rignot, IceBridge science team co-lead and glaciologist at the University of California, Irvine and the Jet Propulsion Laboratory.

As in previous years, Operation IceBridge cooperated with several international research initiatives, including two new ones this year.

In the first, with the University of Alaska, Fairbanks, IceBridge was to fly in a racetrack formation off the coast of Alaska to study the transition between sea ice attached to the coastline and drifting ice.

The second collaboration was with the recently launched European satellite Sentinel-3. Weather permitting, IceBridge was to fly under one or more sections of the spacecraft's orbit.

A view from the plane used in Operation IceBridge, NASA's airborne survey of polar ice, now in its eighth year of campaigns.

NASA recently used satellite imagery to update global coral reef maps, which hadn't been substantially updated since Charles Darwin's work charting them.

The Evolution of Coral Reef Science

Scientists are looking to satellite data to monitor the health of coral reefs, especially in remote regions.

Until relatively recently, global maps of coral reefs hadn't changed significantly from maps produced by Charles Darwin in 1842 based on observations from his expeditions. In 1912, French scientist Louis Joubin updated the maps using information he received in letters from people living near coral reefs around the world.

About 15 years ago, coral reef mapping finally leapfrogged to modern times. A new global map of coral reefs was created with over a thousand Landsat 7 satellite images collected between 2000 and 2003.

But Landsat data is not high-resolution enough to provide the detailed data needed to closely monitor coral reef health.

Frank Muller-Karger, professor of oceanography at the University of South Florida, teamed up with the National Oceanic and Atmospheric Administration Coral Reef Watch program under a 2013 NASA Applied Sciences grant to develop new products using U.S. and international satellites for a coral reef ecosystem stress alert program.

And new instruments are in testing or in the pipeline to help further improve coral mapping in the future. For example, the Hyperspectral Imager for the Coastal Ocean (HICO), which flew on the International Space Station, offered 90-meter spatial resolution, providing detailed images of coral reef regions.

Future hyperspectral data from space will enable high-quality observations that could be used to map the diversity of changing global coastal zones. This will allow scientists to better quantify how organisms change, and ultimately how humans can better use nature to sustain a healthy planet.

Background: first responders from California help search for tsunami victims in Ofunato, Japan, in 2011. Inset: a typical GPS station in southern California, which the Jet Propulsion Laboratory and Scripps Institution of Oceanography are using as part of a new early-warning system for earthquakes.

Rapid Quake Response

As soon as the shaking stops after an earthquake, the most important question for first responders is its location, depth, and magnitude.

"When disaster strikes, the quality of the response—and therefore the number of lives saved—usually comes down to this: how good is the information you're working off? And how quickly can you get it?" explained Rusty Sailors, CEO of LP3, a security firm, and an experienced first responder.

But current methods of quickly determining an earthquake's magnitude, usually through seismic sensors measuring shaking of the crust, remain insufficient.

And the bigger the quake, the less accurate the early analysis from seismic sensors is, often underestimating the magnitude significantly. That can mean that too small an area receives hazard warnings, that those who receive the warning are under-prepared for the actual event, and that authorities will underestimate the tsunami hazard zone.

Authorities and first responders need better data to accurately and quickly assess the risk associated with an earthquake. The Scripps Institution of Oceanography, in collaboration with the Jet Propulsion Laboratory (JPL), looked to space.

The researchers sought to improve earthquake magnitude measurements by collecting data on ground displacement at GPS sites and marrying them with seismic measurements.

To enhance their data, JPL and Scripps have upgraded scientific GPS stations with sensors that monitor for earthquakes while collecting GPS, pressure, temperature, and seismic data in real time across Southern California.

The stations send the information to Scripps via the Internet and radio waves—which travel faster than shock waves—where scientists use the GPS data to measure exactly where and by how much the ground moved during an earthquake. Computer models can then estimate the earthquake's location, magnitude, depth, and tsunami potential, all within minutes, enabling rapid and more accurate earthquake responses than ever before.

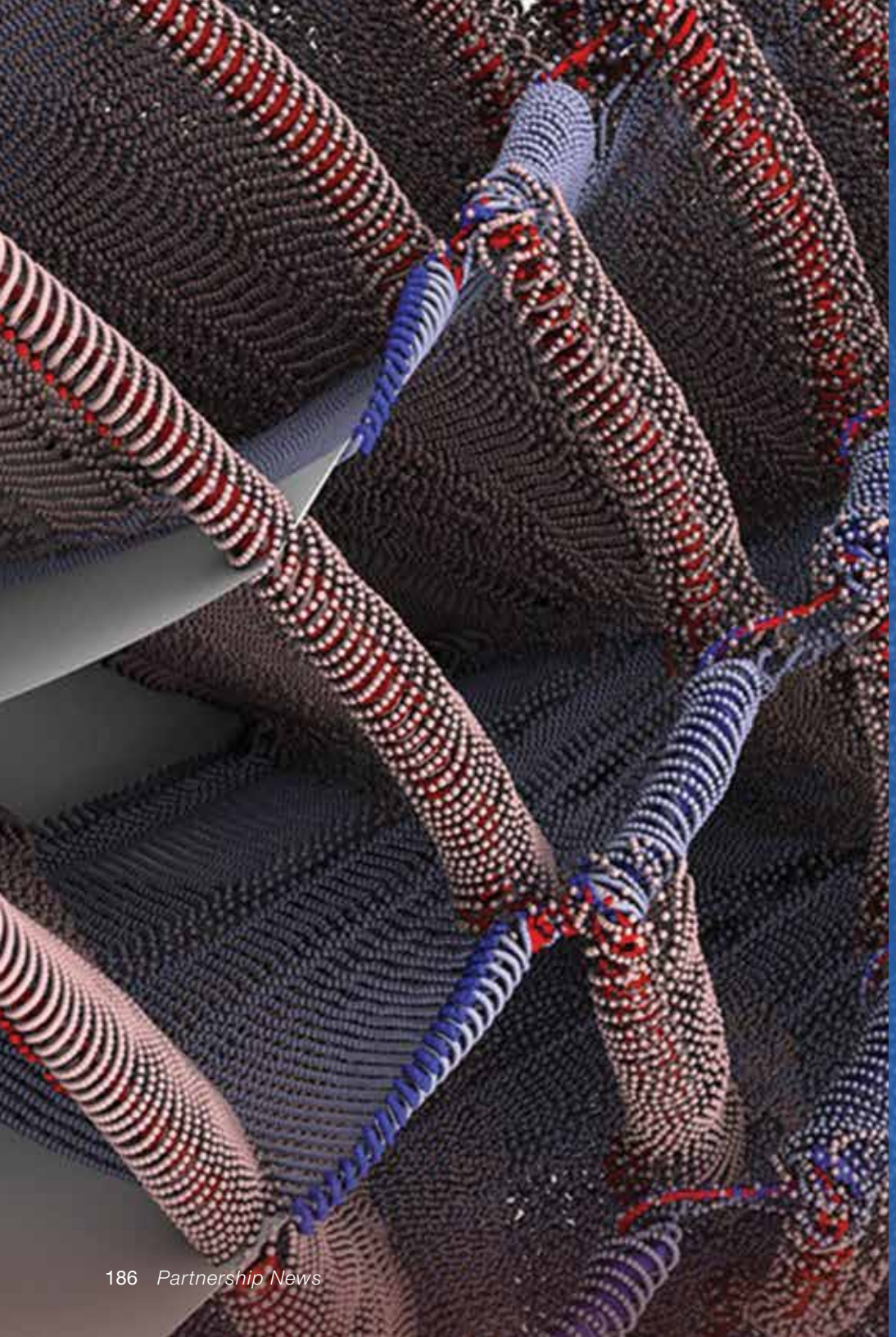
Deer Tracks

Mule deer mothers are in sync with their environment, with reproduction patterns that closely match the cycles of plant growth in their habitat. And new research using NASA satellite data shows that tracking vegetation from space can help wildlife managers predict when does will give birth to fawns.

"We had never tracked the deer population this way, and we had never been able to predict it with such precision," said David Stoner of Utah State University, lead author of a recent study. By measuring the greenness of the mule deer habitat, scientists were able to mark the beginning and peak of the plant growing season—and the fawning season.

"This kind of applied research is very important for making remote sensing data relevant to wildlife management efforts," said Jyoteshwar Nagol, a researcher at the University of Maryland.

Deer have a huge economic impact in the United States, from hunting to crop damage to car accidents. As regional climates shift or droughts occur, deer distributions could change in response to changes in the timing of vegetation green-up.



Greener Flights Are on the Horizon

NASA and partners in the aviation industry are working together to develop new technologies to make flying greener.

One concept studied at Ames Research Center is a new kind of rotor system that has two ultra-thin blades spinning in opposite directions around the outside of a turbofan jet engine.

This unique design allows air to flow more efficiently through the turbofan blades to improve flight performance, reduce carbon emissions, and decrease blade rotation noise.

For the past year, researchers at the NASA Advanced Supercomputing (NAS) facility at Ames have produced first-of-a kind simulations of sound produced by air—aeroacoustics—to reliably predict noise sources for contra-rotating open rotors.

Using computational fluid dynamics methods and the Pleiades supercomputer, the NAS team verified the simulation accuracy and compared sound pressure level ranges with extensive wind tunnel test data from Glenn Research Center and General Electric.

The analysis requires a massive amount of computing power and time. Currently, the NAS team is researching ways to speed up the simulation and analysis process and cut down on computing resources needed to design planes that are more Earth-friendly.

Visualization of the air flow from a contra-rotating, open-rotor simulation created using the Launch Ascent and Vehicle Aerodynamics (LAVA) software framework. Red particles are seeded on the upstream blades, blue on the aft blades. Solid colors are seeded on the tips, while faded colors are on the blade trailing edges. The basket-weave pattern shows where particles interact with each other—one of the sources of blade noise.

NASA officials hope experimental-airplane proving technologies will substantially improve future aircraft while providing major economic benefits. Aircraft concepts include, clockwise from bottom left, electric distributed propulsion, quiet supersonic flight and hybrid wing aircraft.

Generation X-Planes

A new NASA initiative for airplane research could help reduce fuel consumption, emissions, and noise—and even enable commercial supersonic flight.

The Agency's New Aviation Horizons initiative is a 10-year plan to achieve those goals by designing, building, and flying a number of flight demonstration vehicles, or X-planes.

"We're at the right place, at the right time, with the right technologies," said NASA Aeronautics Associate Administrator Jaiwon Shin. "We need the X-planes to prove, in an undeniable way, how that tech can make aviation more Earth-friendly, reduce delays, maintain safety for the flying public, and support an industry that's critical to our Nation's economic vitality."

The 10-year initiative also includes major field tests in collaboration with airlines, airports, and the Federal Aviation Administration to continue improving air traffic flow in the air and on the ground at airports.

It is estimated that billions of dollars are at stake in the global aviation industry as it grows from 3.3 billion passenger trips in 2014 to an estimated 7 billion passenger trips in 2034.

Staying Strong in Space

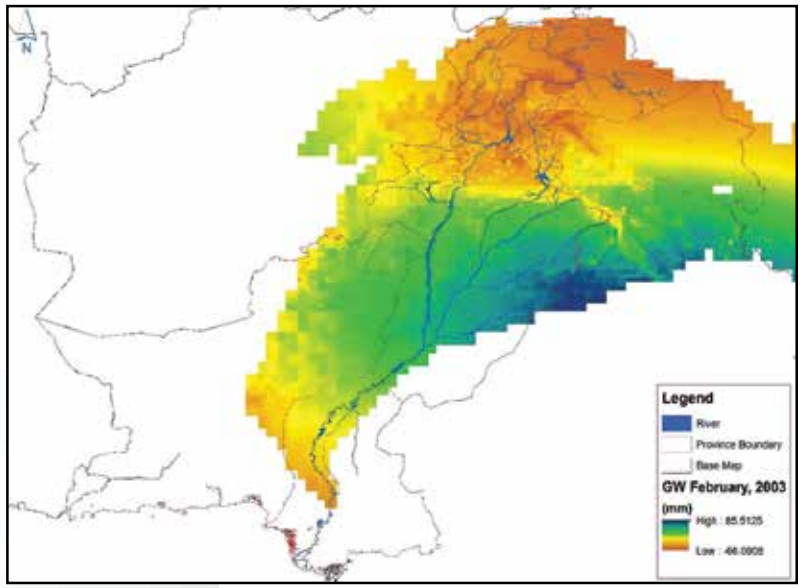
How can spaceflight help researchers better understand muscle and bone diseases and interventions on Earth? When we unload, or remove the force of our body weight from the muscles that normally work against gravity to support us, healthy muscles rapidly atrophy, or waste away and weaken.

"The ability to expose all muscles of an organism to conditions that induce muscle atrophy is not easily achieved on Earth," explained Rosamund Smith, principal investigator of a rodent study on the space station sponsored by Eli Lilly and Company and the Center for the Advancement of Science in Space.

She and her team are studying skeletal muscle, as well as other organ systems, aiming to characterize tissue responses to spaceflight and observe how these changes vary with the length of time spent in microgravity. The findings will advance understanding of the risks of long-term space exploration for astronauts.

Results will also be applied to ongoing discovery efforts at Eli Lilly and Company to seek treatments for serious muscle-wasting diseases and conditions that may help patients afflicted with degenerative diseases to stay strong.

Under the direction of the International Space Station Utilization Office and the Space Biology Project, NASA's Rodent Research Hardware System was developed and built at NASA's Ames Research Center to provide a research platform for long-duration rodent studies in space.



Pakistan water managers used NASA satellite data to produce this map of monthly groundwater changes in the Indus River Basin. Orange and yellow indicate areas where groundwater might be depleted, while blue and green highlight areas where groundwater is being replenished.

Beneath the Surface

Pakistan relies on one of the largest continuous irrigation systems in the world to water its vast farmlands.

But where once farmers were able to depend solely on glacier- and rain-fed rivers and canals, now, thanks to a booming population, the country needs to use groundwater to keep up with demand.

Pakistan's water managers are looking to NASA satellites to help them more effectively monitor and manage that precious resource, thanks to a partnership with engineers and hydrologists at the University of Washington, Seattle.

"Satellites up in space are looking at how much water we have underground, in rivers, or in the atmosphere and are providing routine observations that can help policymakers and on-the-ground managers make informed decisions,"said Faisal Hossain, associate professor of civil and environmental engineering at the University of Washington.

The monthly updates, using freely downloadable data from NASA's Gravity Recovery and Climate Experiment mission, can offer improved flood forecasting as well as indicate areas where groundwater resources are threatened.

Watching the Asian Skies

NASA and the Republic of Korea are working together to advance air pollution monitoring from space.

A study in May and June 2016 aimed to assess air quality across urban, rural, and coastal areas of South Korea using the combined observations of aircraft, ground sites, ships, and satellites.

Findings will play a critical role in the development of observing systems of ground- and space-based sensors and computer models to provide improved air quality assessments for decision makers.

Air quality is a significant environmental concern in the United States and around the world. Scientists are trying to untangle the different contributors to air quality, including local emissions from human activities, pollution from far away, and natural sources such as seasonal fires and wind-blown dust.

"Working with our South Korean colleagues on [this study], we will improve our understanding of the detailed factors controlling air quality, how the processes interact, and how they are changing over time," said James Crawford, a lead U.S. scientist on the project from Langley Research Center.

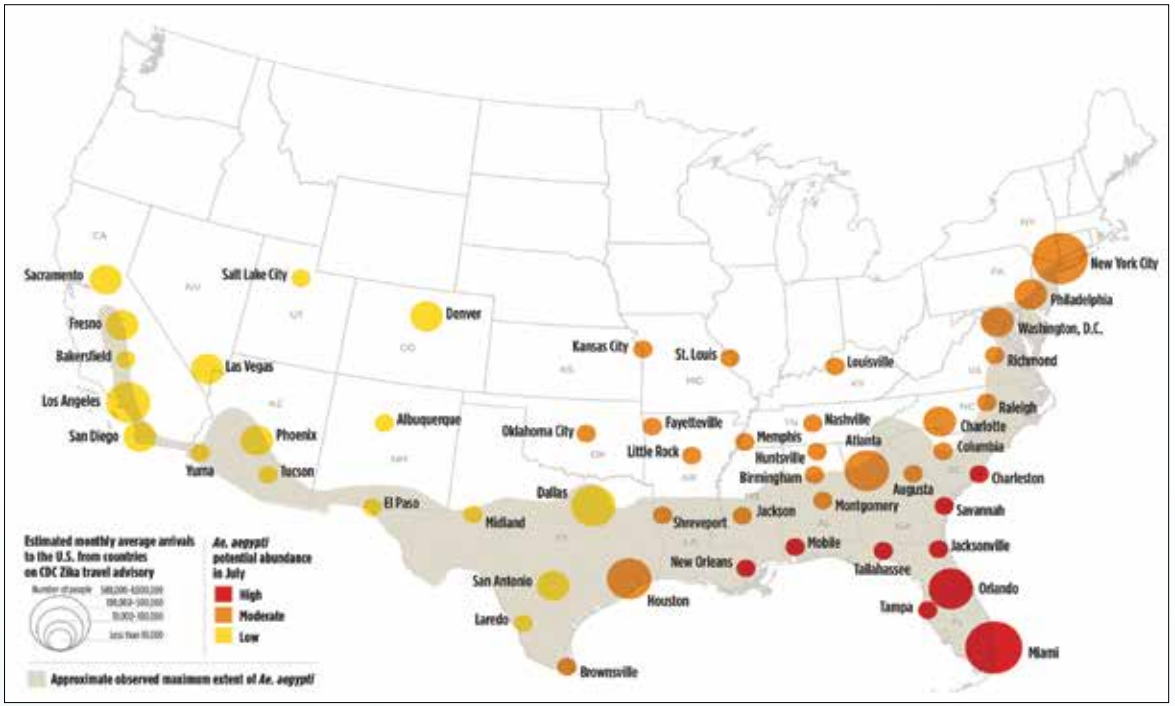
Two NASA research aircraft, the UC-12B (top) and the DC-8, gathered atmospheric data across urban, rural, and coastal areas of South Korea to help improve the ability to monitor air pollution from space.

Forecasting Zika Risk

Scientists at Marshall Space Flight Center partnered with the National Center for Atmospheric Research in Boulder, Colorado, and other institutions to try to better understand the Zika virus and limit the spread of the disease.

The research team looked at key factors—including temperature, rainfall, and socioeconomic factors—to understand where and when a potential outbreak may occur. Their final product, a Zika risk map, can help government agencies and health organizations better prepare for possible disease outbreaks related to the spread of the virus.

"This information can help public health officials effectively target resources to fight the disease and control its spread," said Dale Quattrochi, senior research scientist at Marshall.



A risk-assessment map shows *Aedes aegypti* potential abundance for July 2016 and the monthly average arrivals to the United States by air and land from countries on the Center for Disease Control Zika travel advisory.

Peeking through the Clouds

Combining satellite images with novel algorithms, scientists and engineers at Langley Research Center can identify where severe winds, hail, or tornadoes are more likely to occur.

Thunderstorms form when warm, moist air rises rapidly into the atmosphere. When the rising air, or updraft, hits the stratosphere without penetrating it, it forms the flat tops of cloud formations known as cumulonimbus incus, or anvil clouds. This type of cloud can be an indicator of dangerous weather on the ground.

But anvil tops can be miles wide. Researchers at Langley, in partnership with the National Oceanic and Atmospheric Administration and other international agencies, found that a key factor was finding the strongest updrafts of air, which are strong enough to punch through the stratosphere. These create lumps in the cloud top, indicating areas where strong thunderstorms—and sometimes hail and tornadoes—usually occur.

Using infrared imagers on satellites, the researchers can spot the lumps, which emit less heat than other clouds in lower regions of the atmosphere. Combine this data with powerful software engineering and voila: almost instant forecasts.

Taken during the Deep Convective Clouds and Chemistry campaign, the above image shows a side view of an intense updraft punching through a cumulonimbus cloud "anvil." Below, a similar cloud formation is shown in a photograph taken from the ISS.

Left: Onboard the ISS, NASA astronaut Kjell Lindgren prepares the IMAX camera over an empty spacesuit for a shoot. Below: *Beautiful Planet* narrator Jennifer Lawrence, fourth from right, joins space station astronauts who shot footage for the film at the world premiere in New York City in April 2016. From left, former NASA astronaut Scott Kelly, European Space Agency astronaut Samantha Cristoforetti, Lawrence, and NASA astronauts Barry Wilmore, Kjell Lindgren, and Terry Virts.

The Big Picture

The view doesn't get any better than looking at Earth from the International Space Station's Cupola—and this year moviegoers on Earth got a chance to enjoy the sights.

A Beautiful Planet—a collaboration with IMAX and featuring narration by Hollywood's Jennifer Lawrence—stars Earth as seen from space by astronauts and cosmonauts aboard the orbiting station.

Shot over 15 months, the documentary highlights the effects humanity has had on the globe over time, from the gradual depletion of the Colorado River Basin to the effects of greenhouse gasses in the atmosphere to deforestation.

The astronauts show us a glimpse of an Earth that is vibrant in nature but also fragile, hoping to inspire positive change on our home planet as a result of their work.

‘Fugitive’ Emissions, Caught by a Drone

As part of a project to improve safety in the gas pipeline industry, researchers have successfully flight-tested a miniature methane gas sensor developed by NASA’s Jet Propulsion Laboratory (JPL) on a small unmanned aerial system, or drone. The sensor, similar to one developed by JPL for use on Mars, enables detection of methane with much higher sensitivity than previously available for the industry in hand-carried or drone-deployable instruments.

Researchers from JPL and the Mechatronics, Embedded Systems, and Automation Lab at the University of California, Merced, conducted the flight tests in late February 2015. They flew a small drone equipped with the open path laser spectrometer (OPLS) sensor at various distances from methane-emitting gas sources. Tests were done in a controlled setting to test the accuracy and robustness of the system.

The tests were conducted in central California at the Merced Vernal Pools and Grassland Reserve and were funded by Pipeline Research Council International. The jointly conducted test of NASA’s OPLS sensor is the latest effort in a methane testing and demonstration program conducted on various platforms since 2014. The ability of the OPLS sensor to detect methane in parts per billion by volume could help the pipeline industry more accurately pinpoint small methane leaks.

Advanced capabilities provided by drones, particularly enhanced vertical access, could extend the use of methane-inspection systems for detecting and locating methane gas sources.

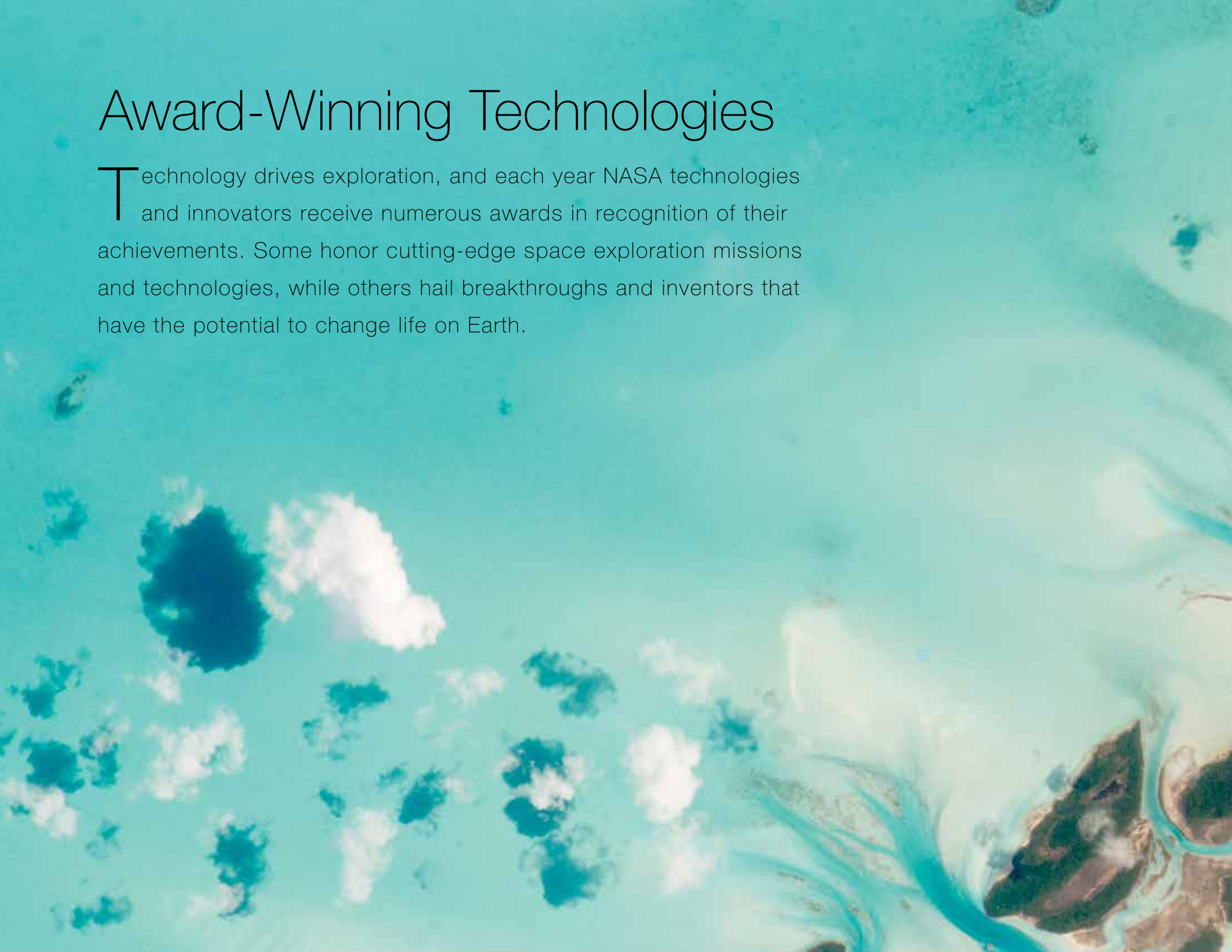
“These tests mark the latest chapter in the development of what we believe will eventually be a universal methane monitoring system for detecting fugitive natural-gas emissions and contributing to studies of climate change,” said Lance Christensen, OPLS principal investigator at JPL.

A Jet Propulsion Laboratory mini methane gas sensor is flight tested on a small unmanned aerial system under a project to improve energy pipeline industry safety. The sensor enables methane detection with higher sensitivity than previously available for the industry in hand-carried or drone-deployable instruments.

Image courtesy of University of California, Merced

Award-Winning Technologies

Technology drives exploration, and each year NASA technologies and innovators receive numerous awards in recognition of their achievements. Some honor cutting-edge space exploration missions and technologies, while others hail breakthroughs and inventors that have the potential to change life on Earth.



Double Honor for Dawn Mission

NASA's Dawn project team recently earned two prestigious awards, honoring its successful mission to giant asteroid Vesta and dwarf planet Ceres.

The first award, the National Aeronautic Association Robert J. Collier Trophy, is presented annually "for the greatest achievement in aeronautics or astronautics in America, with respect to improving the performance, efficiency, and safety of air or space vehicles, the value of which has been thoroughly demonstrated by actual use during the preceding year." The Dawn project team will be added to the list of more than a century of recipients engraved on the eight-foot-tall trophy at the Smithsonian National Air and Space Museum in Washington.

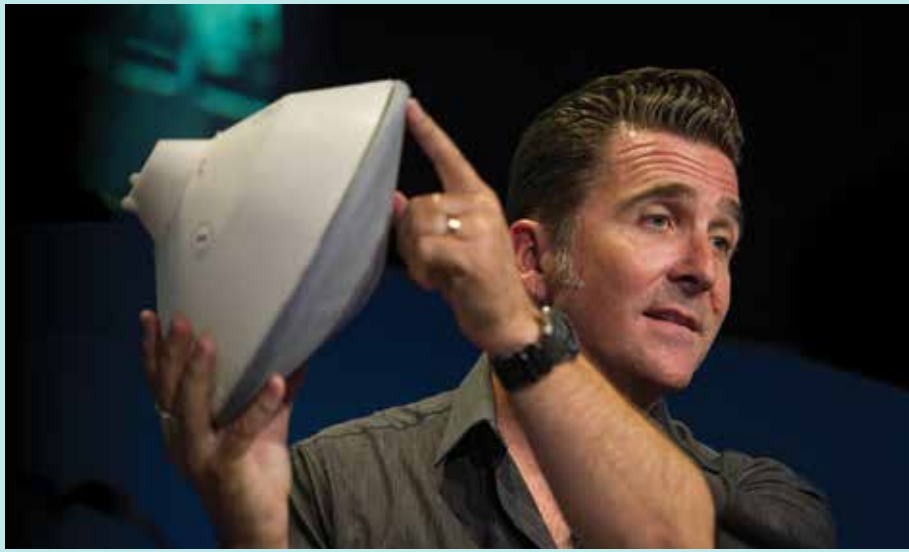
The team was also honored with the National Space Club and Foundation's Nelson P. Jackson Award, presented annually for "a significant contribution to the missile, aircraft, or space field."

"We are grateful for this tremendous honor, recognizing the hard work, determination, and unwavering commitment of this team to achieve mission success and advance the spirit of exploration," said Robert Mase, Dawn project manager at the Jet Propulsion Laboratory.

The spacecraft is currently orbiting Ceres, where it will remain after its primary mission ends.

Among other achievements, Dawn became the first spacecraft to orbit two bodies beyond Earth, thanks in large part to the efficiency of its ion propulsion system. The probe is currently orbiting dwarf planet Ceres, where it is scheduled to remain through the end of its mission.

Engineer Honored for Curiosity's Innovative Mars Landing



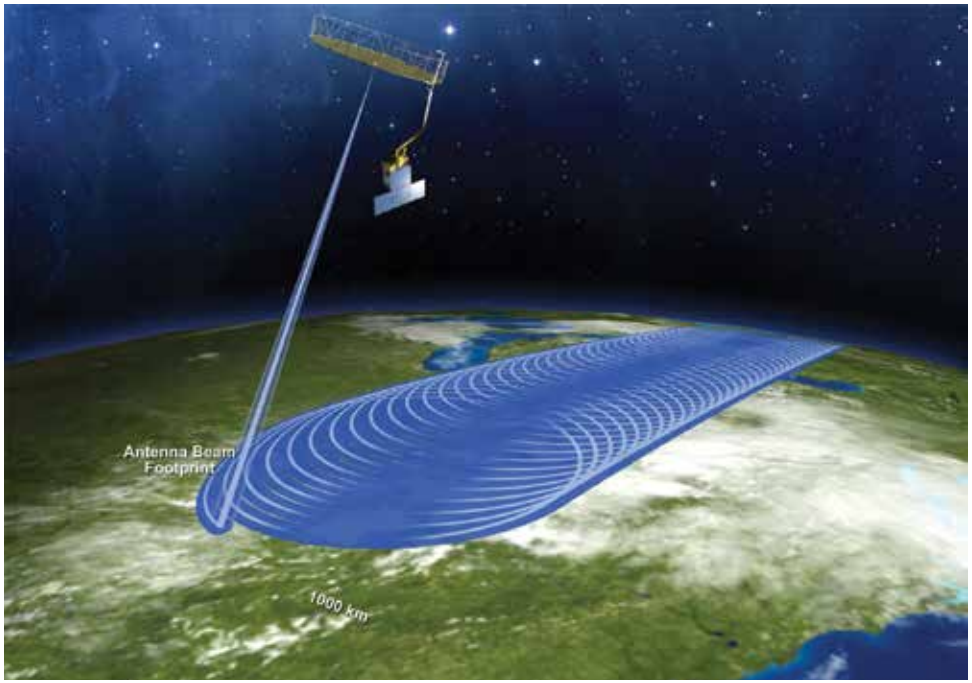
Adam Steltzner, who helped pioneer the breakthrough technique for landing a one-ton rover on Mars, was honored with admission into the National Academy of Engineering.

Election to the academy is among the highest professional distinctions for an engineer. Academy membership honors those who have made outstanding contributions to "engineering research, practice, or education" and to "the pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education."

Steltzner, an engineer at the Jet Propulsion Laboratory (JPL), was involved in the design of and led the team that developed Curiosity's entry, descent, and landing system, which included the innovative sky crane landing system that placed the rover on Mars in August 2012.

The technology will also be used to land the Mars 2020 rover.

Also elected into the National Academy of Engineering was Paul Dimotakis, who served as JPL's chief technologist from 2006–2011. He was recognized for his contributions to the fluid mechanics of jet propulsion and other processes involving turbulence, mixing, and transport.



NASA's Soil Moisture Active Passive (SMAP) mission launched in January 2015 to map global soil moisture and detect whether soils are frozen or thawed. The data it has returned since launch was used in an innovative—and now award-winning—cooperation model to share insights between U.S. Government agencies.

SMAP Mission Recognized for Pioneering Cooperation Model

A mission using a NASA satellite to provide daily soil moisture measurements from around the world was recognized for its pioneering inter-agency cooperation efforts, earning a 2016 Federal Laboratory Consortium for Technology Transfer Award.

Data from the NASA Soil Moisture Active Passive (SMAP) satellite is used by dozens of Federal agencies to assess and monitor hydrologic phenomena.

U.S. Department of Agriculture (USDA) and NASA scientists worked from the start to engage SMAP end users and to build a broad user base for SMAP applications.

USDA scientists served on the SMAP Science Team and provided leadership to the SMAP Applications Working Group, using their knowledge of agricultural stakeholder needs to anticipate how the SMAP data might be useful. NASA scientists, for the first time, provided simulated data through a user-friendly portal so users had the opportunity to conduct simulated applied research and build prototypes.

This combination of respective agency expertise, facilities, and commitment enabled an unprecedented transfer of SMAP technology to users and critical feedback to the mission to improve product specifications and distribution of applications.

This was a first-time, one-of-a-kind program that has since been implemented in every NASA Earth Observation mission since SMAP.

FLC Celebrates NASA Tech Transfer

The Federal Laboratory Consortium for Technology Transfer honored two of NASA's field centers, Armstrong Flight Research Center and the Jet Propulsion Laboratory, with three Outstanding Technology Development awards in 2015, recognizing their efforts to move Federal technologies out of the labs and into the marketplace.

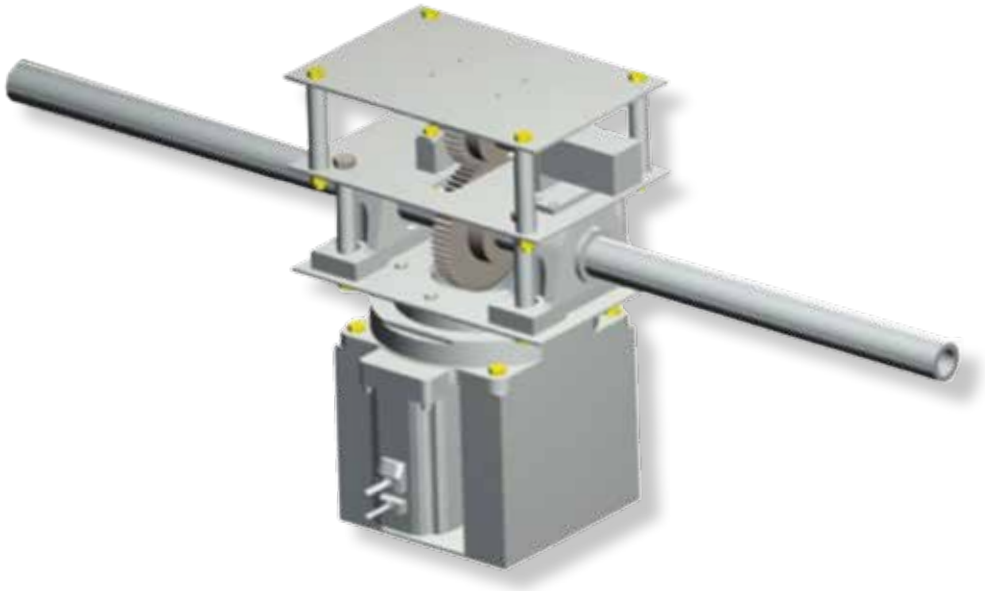
Armstrong's Collision Avoidance System

Researchers at NASA's Armstrong Flight Research Center have dramatically improved existing ground collision avoidance technology for aircraft.

Some 100 people die each year in the United States alone from aircraft accidentally flying into the ground, a mountain, a body of water, or another obstacle.

Warning systems have virtually eliminated the problem for large commercial air carriers, but not as much for fighter aircraft, helicopters, and general aviation.

NASA's improved ground collision avoidance system (iGCAS) leverages leading-edge fighter safety technology, adapting it to civil aviation use as an advanced warning system. The algorithms in Armstrong's technology also have been incorporated into an app for tablets and other mobile devices that can be used by pilots in the cockpit, enabling significantly safer general aviation.



Armstrong's Auto-Tracking Antenna

An innovative, low-cost antenna-mounting platform, developed at Armstrong Flight Research Center, addresses an unmet need in the unmanned aerial vehicle (UAV) market.

Capable of aiming four or more interchangeable antennas of any type, this unique, continuously rotating platform is portable and can position and hold nearly 60 pounds of antennas and radios at its full rated speed.

It is ideal for use with any moving system needing to transmit large quantities of data over one or more radio frequency links. Possibilities include maintaining data links with UAVs and other aircraft used for academic and government research as well as communicating with marine ships in line of sight and tracking satellites in low-Earth orbit.

NASA expertise played a key role in the development of the world's first 3D-image-producing endoscope suitable for use in brain surgery.

JPL's Mini 3D Camera for Brain Surgery

A tiny camera that could produce 3D images from inside the brain would help surgeons see more intricacies of the tissue they are handling and lead to faster, safer procedures.

An endoscope with such a camera is being developed at the Jet Propulsion Laboratory (JPL) for the Skull Base Institute, which has licensed the technology from the California Institute of Technology, which manages JPL for NASA.

Researchers have demonstrated a laboratory prototype of MARVEL, which stands for Multi-Angle Rear-Viewing Endoscopic Tool; the next step is a clinical prototype that meets the requirements of the U.S. Food and Drug Administration.

Nanotubes and Leak Detection Tape Receive Top NASA Honors

The two winners of NASA's Invention of the Year Award for 2016 were a technology to produce high-quality boron nitride nanotubes, which form a highly heat-resistant material, and a tape that allows the simple and accurate identification of dangerous hydrogen leaks.

The first boron nitride nanotubes (BNNTs) were synthesized in 1994, but they were difficult to make on a larger scale. Langley Research Center's breakthrough discovery is the first to produce high-quality BNNTs without any catalyst at a scalable amount.

The BNNTs produced from this process are lightweight, stable, and strong. This heat-resistant material can be used at high service temperatures and for radiation shielding. The patents have been licensed by BNNT LLC, which has continued to improve production efficiency.

Kennedy Space Center's hydrogen leak detection tape—officially, Hydrogen Sensing Pigments in Manufactured Polymer Composites—is a chemochromic sensor for detecting hydrogen, a combustible gas.

This low-cost tape can be used in many commercial and government applications, such as in aerospace, oil and gas production, chemical and power plants, and other industries. It is licensed to HySense Technology LLC, which sells the product as Intellipigment tape.

Both commercial products were featured in *Spinoff* 2016.

A tape that changes color in the presence of hydrogen was developed at Kennedy Space Center, where it was used to monitor pipelines of rocket fuel to locate leaks prior to Shuttle launches. Today, the tape has been commercialized and is sold to many aerospace, oil and gas, chemical, and power companies.

New Antenna Approach Gets Top R&D Honor

A new approach to manufacturing antennas, developed at Glenn Research Center and which could have a huge impact on Earth and space communications, earned an R&D 100 Award as one of the top technology products of the year.

The winning team was honored in the IT and Electrical category for a revolutionary polyimide aerogel-based antenna that is significantly lighter and longer-range than previous antennas.

On Earth, aerogel antennas can increase safety in collision avoidance systems for cars. In air and space platforms, aerogel-based antennas will free up space and reduce weight from antennas aboard aircraft, satellites, or spacecraft.

The lightweight, powerful antennas could also be used for biomedical applications, such as wearable antennas, and in radio frequency identification tags in the retail industry (see page 164).

NASA researchers contributing to this revolutionary technology include Mary Ann Meador and Felix Miranda, along with team members Nicholas Varaljay, Carl Mueller (formerly of Vencore), Frederick Van Keuls (Vantage Partners), and Baochau Nguyen (Ohio Aerospace Institute).

Another Glenn team was a finalist in the Analytical and Test category for work on a supercooled liquid water content sensor for radiosondes. The lightweight, inexpensive sensors are the only technology for measuring icing conditions in the atmosphere with weather balloons instead of instrumented aircraft (see page 78).

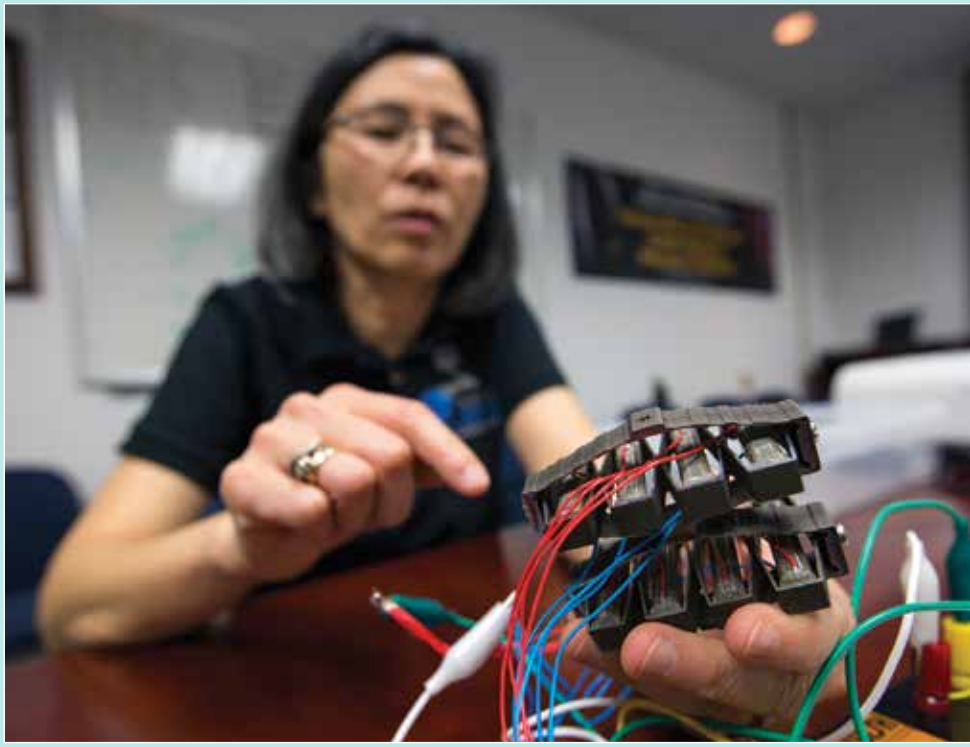
The NASA radiosonde sensor team includes Michael King, Andrew Reehorst, and John Bognar (Anasphere Inc.).

Energy-Harvesting Device Wins Industry Award

A technology developed by Langley Research Center to harvest energy from the vibrations of a piezoelectric device won an award for Best Technical Development within Energy and Harvesting at the 2015 IDTechEx Show.

The technology, called a multistage force amplification piezoelectric energy harvester, dramatically increases the amount of power captured from a piezoelectric device, from milliwatts to watts. The increase means that, for example, vibrations in a car's dashboard could produce enough power to light up one of the vehicle's instrument panels.

The technology was developed in collaboration with the National Institute of Aerospace, Virginia Polytechnic Institute and State University, and North Carolina State University.



Mia Siochi, a senior materials scientist at NASA Langley, holds one of the piezoelectric energy harvesters she helped invent.

Space Technology Hall of Fame Inducts Two NASA Spinoffs

Two technologies with origins at NASA, now saving lives on Earth, are the Space Technology Hall of Fame's newest inductees. Established in 1988 by the Space Foundation, the hall of fame aims to increase public awareness of the benefits that result from space exploration programs and to encourage further innovation.

Huge Advance for Heart Irregularities

Medtronic's revolutionary insulation for treating heart irregularities was developed by a NASA Langley Research Center engineer researching new materials for lightweight rocket bodies. Robert Bryant noticed that an experimental polymer that should have turned into a powder instead remained soluble.

Bryant developed what is now known as LaRC-SI, a durable thermoplastic readily fabricated in very thin form that it is biologically nonreactive and solvent-resistant.

Convinced of the enormous benefits of this new material, Medtronic spent more than 10 years and tens of millions of dollars to secure approval from the U.S. Food and Drug Administration (*Spinoff* 2008).

The thinner, more flexible material allowed surgeons to get electrical impulses into areas previously too difficult to reach, and it was more resilient, reducing lead failure over time. The new material has saved lives and improved quality of life for thousands.

LaRC-SI, a material discovered more than 20 years ago by Robert Bryant of Langley Research Center, has improved the function of pacemakers used by thousands of cardiac patients.

“ Discovering a little **water brings war,** but discovering a lot **of water can** bring **peace, because** everyone can **share it.”**

— Alain Gachet, Radar Technologies International

A High-Tech Divining Rod

Alain Gachet founded Radar Technologies International (RTI) in 1999 to use satellite-generated remote sensing data to locate precious metals, but he discovered he could use the same data to find water underground.

Gachet created the WATEX system, using NASA’s Shuttle Radar Topography Mission, NASA’s Spaceborne Imaging Radar, and the joint NASA and U.S. Geological Survey’s Landsat program to pinpoint promising spots to drill new wells.

The first significant success came in 2004 during the Darfur crisis in western Sudan, which forced some 250,000 people into refugee camps. The United Nations High Commissioner for Refugees contacted RTI, and over the next four months, RTI located enough water to sustain the camp.

Prior to RTI’s involvement, aid groups responsible for locating water sources had a success rate of around 33 percent. Using WATEX, success soared to 98 percent.

Later, Gachet uncovered an unprecedented 66 trillion gallons of water in two aquifers underneath one of the world’s most destitute regions, Turkana County in northern Kenya (*Spinoff* 2015). The discovery has the potential to improve millions of lives for generations to come.

Women in Turkana County, Kenya, come with containers to gather newly discovered water from a drilled well in the Lotikipi basin. Alain Gachet, founder of Radar Technologies International, made an unprecedented discovery of water reserves in the region in 2013.

Tech Briefs' Create the Future Design Contest Honors Five Field Centers

For more than a decade, *NASA Tech Briefs* magazine has aimed to stimulate and reward engineering innovation with its Create the Future Design Contest. In the most recent judging, NASA entries won top honors in four of the seven categories, and another entry was chosen as part of the top 100.

Langley's Compact Long-Reach Robotic Arm

A robotic arm with lightweight joints that provide a long reach and wide range of motion, developed by Langley Research Center, won in the machinery, automation, and robotics category.

The arm, ideal for use in aquatic environments or for manipulation of light terrestrial loads, consists of articulating booms connected by antagonistic cable tension elements. Current efforts are focusing on a prototype and a subsystem to test the unique robotic architecture.

Inventors have developed an algorithm to scale the arm based on tip load, reach, and tip deflection inputs for any given application.

NASA's compact long-reach robotic arm could find applications in ship-to-harbor or ship-to-ship docking, floating barrier deployments, subsea cable inspections, and more.

Luz Calle, the technical lead for Kennedy Space Center's Corrosion Technology Laboratory, checks out sample tiles at the Kennedy's Beachside Corrosion Test Facility.

Kennedy's Smart Coating for Corrosion

The automotive and transportation category win went to Kennedy Space Center's smart, environmentally friendly coating system for early detection and inhibition of corrosion.

The coating detects corrosion in its early stages, inhibits it, and, if necessary, repairs itself. The smart coating is based on the controlled release of corrosion inhibitors and indicators from specially formulated microcapsules and particles pioneered by NASA.

Armstrong's High-Speed Fiber Optic Sensing

Armstrong Flight Research Center's fiber optic sensing system (FOSS), a major breakthrough in high-speed operational monitoring and sensing, won in the electronics category. The system delivers measurements in the most demanding environments confronted by aerospace, automotive, and energy sectors.

The system offers unprecedented density, with each of the eight 40-foot hair-like optical fibers providing up to 2,000 data points. All sensors can gather up to 100 samples per second, with several dozen able to gather up to 35,000 samples per second.

Also earning an honorable mention for Armstrong, in the aerospace and defense category, was the center's aircraft collision prevention system, which could prevent some 100 deaths each year in the United States among general aviators.

JPL's Cheaper, More Efficient Methanol Fuel Cell

The Jet Propulsion Laboratory has developed a next-generation, direct-feed fuel cell that is cleaner, cheaper, and more efficient than existing fuel cells, earning an honorable mention in the electronics category.

Methanol fuel cells use an oxidation and reduction reaction to generate electrical power without polluting the air or burning nonrenewable fossil fuels.

This fuel cell is ideal for vehicles and other portable applications, because it permits the use of high-performance alternative fuels that can be stored and transported with ease.

Stennis' Low-Power, Efficient System for Intermittent Monitoring

Also chosen among the top 100 entries was a system from Stennis Space Center that can be used for long-term monitoring of events, such as the temperature in a particular location in a building or the strain at a specific point on a bridge.

The system includes a base station and at least one sensor unit, which lies dormant until it receives a voltage trigger. When activated, the sensor takes a measurement, transmits the data to the base station, and then returns to its dormant state.

Wireless sensors developed at Stennis Space Center, originally designed to monitor rocket testing, can be used on a variety of structures to measure strain, temperatures, position, direction, and more.

Kennedy Engineer Earns Spot in Florida Inventors Hall of Fame

Jacqueline Quinn, an environmental engineer at Kennedy Space Center and the inventor of NASA's most licensed and recognized technology for groundwater remediation, was honored with a spot in Florida's Inventors Hall of Fame.

The hall of fame honors and celebrates inventors whose achievements have advanced the quality of life for Floridians and the Nation.

Quinn's groundwater remediation method, called Emulsified Zero Valent Iron (EZVI), is an award-winning, cost-competitive, environmentally safe method to remove contaminants from groundwater and has been successfully used across Florida, Arkansas, Tennessee, and North Carolina (*Spinoff* 2005, 2010).

She also created two methods, called AMTS and SPEARS, to remove cancer-causing PCBs (polychlorinated biphenyls) from materials, soils, and sediments.

In all, Quinn holds 12 U.S. patents, and her technologies have been licensed by companies throughout the United States and internationally.

NASA Honors Ames and Johnson with Software of the Year Awards

Two projects shared the top prize in NASA's most recent Software of the Year competition, Ames Research Center's NEQAIR, which calculates radiation, and Johnson Space Center's navigation and control software for the Orion spacecraft.

Each of NASA's 10 field centers nominated a technology representing the best software from their respective centers. "The final decisions were difficult to reach as the nominations were all outstanding," the Inventions and Contributions Board said in a release announcing the results.

NEQAIR, or Nonequilibrium Air Radiation, which has been NASA's main radiation code for the last 30 years, was upgraded in 2013 and 2014, both in physics and computational efficiency. Its accurate prediction of radiative heat flux allows for efficient design of heat shields with minimal mass, allowing missions to carry heavier payloads and experiments while assuring the astronauts and robotic landers will be safely shielded.

The Orion Crew Exploration Vehicle's onboard Guidance, Navigation, and Control flight software was developed to a class-A, human-spaceflight-ready standard. The technology uses a MATLAB/Simulink tool suite to embrace a model-based development approach.

Two additional software programs, the Data Optimization via Genetic Ordering System developed at the Jet Propulsion Laboratory and Airborne Doppler Wind Lidar Post Data Processing Software from Langley Research Center, were also honored as runners-up.

Greener Cleaner Wins GreenGov Presidential Award

An innovation in precision cleaning methods that avoids environmentally damaging solvents was honored with the GreenGov Presidential Award.

GreenGov Presidential Awards honor Federal teams, programs, or projects that exemplify President Barack Obama's call for a clean-energy economy. Principal investigators Kathleen Loftin and Paul Hintze received the award on behalf of Kennedy Space Center's Chemistry Team at the White House.

The team developed two different processes that can clean space hardware components without any liquid solvents.

The supercritical fluid extraction method uses carbon dioxide, compressing and heating it to the point at which it becomes a supercritical fluid, which has properties of both liquids and gas and acts like a chemical compound.

In the plasma cleaning method, the part to be cleaned is placed inside a chamber of air. When subjected to high energy levels, the gas converts to a plasma, which reacts to the part's surfaces and knocks away contaminants and other impurities.

"Our belief is that if you can do something in the right way, and in a sustainable way, you can save money and help the environment," Loftin said.

Spinoffs of Tomorrow

While NASA creates many technologies that have the potential to improve life on Earth, it's usually up to American businesses and entrepreneurs to bring these innovations to market. In this section, you can read about 20 technologies that are ripe for use by industry and available for licensing. To learn more about any of these technologies, including how to license them or partner with NASA to develop them further, please visit http://technology.nasa.gov.

Ames

Advanced Wind Energy Collection Components

Electrode and composite materials improve piezoelectric conversion of wind to energy

Thin-film, piezoelectric materials generate a small voltage whenever they are deformed, making them suitable for tapping energy from freely available resources such as the wind. Yet their low energy-production levels and lack of electrode durability have hampered development. NASA researchers have invented a system, method, and device for improving the performance and increasing the lifespan of small-form-factor, thin-film-electrode piezoelectric devices capable of interacting with wind to power wearable devices and stretchable electronics.

The NASA researchers integrated two innovations into this unique piezoelectric device. First, they combined polyvinylidene flouride (PVDF) with a metal oxide to improve conductance. Second, they designed a new carbon electrode to improve durability and reduce susceptibility to fatigue while retaining flexibility. Additionally, to integrate the carbon nanotube components, they use a polymer-to-polymer design that eliminates the need for adhesion layers. A prototype device generated one watt of power in 15 mph winds with a single layer of PVDF measuring 4 by 12 inches and 50 micrometers thick, sandwiched between two thin electrode films. A rectifier converts the AC signal into a DC signal and stores the charge in a capacitor. This electric power can be used for low-power-consuming devices such as inaccessible sensors.

Benefits

- The metal oxide improves conductance
- Carbon-based electrodes improve durability
- Polymer-to-polymer design eliminates the need for an adhesion layer
- Can be stretched while still maintaining functionality
- Small, lightweight
- High conversion efficiency

Applications

- Wearable electronics
- Remote or inaccessible sensors
- Wind energy harvesting
- Mechanical energy harvesting

Soil Remediation with Plant-Fungal Combinations

Electrode and composite materials improve piezoelectric conversion of wind to energy

Plant-fungus combinations can vary in their efficacy in removal of fuel and related contaminants from soil. Selection of the most effective combination of plants and fungi is important, as some fungi die off in contaminated soils. A set of enzymes from fungi specifically adapted to conditions in contaminated soils and use of native plant-fungal combinations is a huge advantage. Ectomycorrhizal (EM) remediation uses the abilities of ectomycorrhizal fungi to oxidize phenolic compounds. This can be adapted to other ecosystems through assessments of the EM community in each site.

EM fungi enhance the growth of trees in contaminated soils. They impart resistance to soil extremes such as high temperature, high acidity, and heavy metal contamination. EM fungi in the genera Russula and Piloderma up-regulate enzyme genes in response to changes in host physiological conditions. In response to phenolic soil contamination, they increase production of enzymes that oxidize these compounds when the host tree is partially defoliated, which can be performed each year as maintenance.

Benefits

- Increased resistance to environmental extremes
- Fast response, high selectivity
- Enhances naturally occurring species' ability to decontaminate soil
- Cost effective and low-maintenance
- Flexibile platform

Applications

- Oil and gas industry
- Environmental remediation
- Phytoremediation
- Enzymatic bioremediation
- Cleanup of soil contamination by spills of solvents, including diesel fuels
- Habitat restoration

Armstrong

Preliminary Research Aerodynamic Design to Lower Drag

New wing design exponentially increases aircraft efficiency

Innovators at Armstrong Flight Research Center are experimenting with a new wing design that removes adverse yaw and dramatically increases aircraft efficiency by reducing drag. Known as the Preliminary Research Aerodynamic Design to Lower Drag (PRANDTL-D) wing, this design addresses integrated bending moments and lift to achieve drag reduction. Adverse yaw is handled through fine wing adjustments rather than the vertical tail. The technology could significantly increase total aircraft efficiency by optimizing aircraft configuration through reduction in size or removal of the vertical tail as well as reduction of structural weight.

The engineers built on the 1912 research of German engineer Ludwig Prandtl. The key is reducing the drag of the wing through use of a bell-shaped spanload, as opposed to the conventional elliptical spanload. Designers used a sharply tapered wing with less wing area than the comparable elliptical spanload wing. The wing has more span and less area, resulting in an immediate 12 percent drag reduction. Furthermore, using twist to achieve the bell spanload produces thrust at the wing tips. The result is that the aircraft rolls and yaws in the same direction as a turn, eliminating the need for a vertical tail.

Applications to wind turbines and fans are also being explored.

Benefits

- Reduces adverse yaw when correcting for roll, increasing efficiency and safety
- Improves fuel efficiency by allowing aircraft to fly faster
- Requires no vertical stabilizers, easing production

Applications

- Mid-sized commercial aircraft
- Drones, unmanned aerial vehicles
- Turbines
- Energy delivery systems

Optical Waveguide Fiber Bragg Grating

Grating acts as sensor to detect and map magnetic fields

Innovators at Armstrong Flight Research Center have developed an optical waveguide fiber Bragg grating (FBG) that is sensitive to an external magnetic field. The technology allows direct coupling of the external field to the electromagnetic wave propagating in the fiber, bypassing the need to first measure strain. In contrast to other FBG-based methods that detect external fields via a mechanical change, this innovation uses ferromagnetic nanoparticles to achieve a direct coupling of the external field to the optical behavior of the fiber. Thus, the technology can detect and map magnetic fields.

The innovation leverages Armstrong's patented FBG interrogation system, which enables a diverse set of engineering measurements in a single, compact system. In addition to magnetic fields, other measurements include structural shape and buckling modes, external loads, and cryogenic liquid levels.

Benefits

- Reduces the effects of extraneous thermal and mechanical influences
- Lighter and more compact than many comparable devices
- Allows high spatial resolution maps of magnetic fields

Applications

- Military and homeland security detection of explosive devices
- Aerospace navigation, observations, altitude sensing
- Ground transportation navigation, backup for satellite GPS system
- Electromagnetic receptors/antennas
- Mineral exploration
- Oil and gas drilling
- Geophysical surveys
- Archaeology
- Earth tectonics

Glenn

Advancements in Nanomaterials

New materials and methods to make nanomaterials versatile, reliable, and effective

Innovators at Glenn Research Center have developed a suite of materials and methods to optimize the performance of nanomaterials by making them tougher, more resistant, and easier to process. Glenn's scientists are making improvements at all stages of nanomaterial production, from finding new ways to produce nanomaterials, to purifying them, to devising techniques to incorporate them into matrices, veils, and coatings. These advances can be used to deposit protective coatings for textile-based composite materials, layer carbon nanotubes for reinforcement, upgrade the properties of carbon ceramic matrix composites, and integrate nanomaterial fibers into polymer matrix composites.

One patented technology facilitates the exfoliation of hexagonal boron nitride, useful as a lubricant and found in substances from cosmetics to pencil lead. Another is a novel method to purify nanomaterials, making them more reliable and predictable.

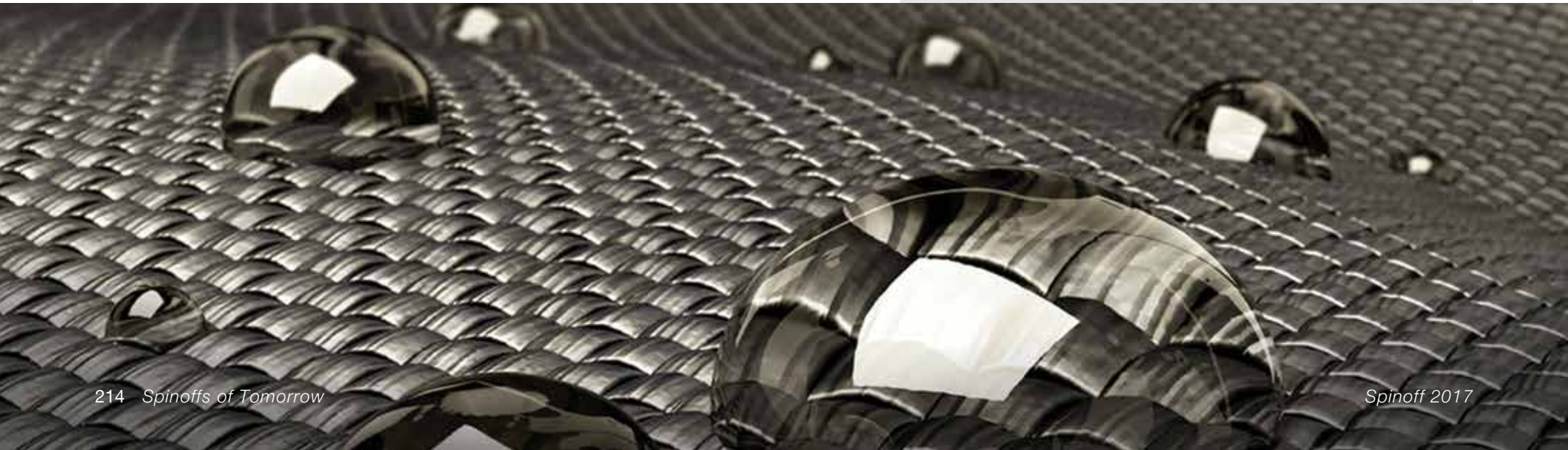
Glenn researchers have also developed new ways to use nanomaterials in fabrication. One technique creates a nanocomposite that has increased strength and stiffness without sacrificing toughness in the cured epoxy. Another centers on a new method to continuously apply a coating of nanofiber material to a composite material. The researchers also have invented a method for incorporating fibers into a polymer matrix composite structure.

Benefits

- Improved strength, ductility, glass transition temperature, and conductivity
- Removal of residue impurities in nanomaterials that cannot be taken out by conventional processes
- Increased toughness without interfering with other characteristics or performance
- Enhanced bonding with matrix
- Altered electrical or thermal conductivity

Applications

- Carbon nanotubes for aircraft, electronics
- Graphene for ultracapacitors, electronic sensors
- Nanocomposites for batteries, windmill blades
- Nanofibers for textiles, furniture
- Nanoparticles for fuel cells, solar cells
- Nanowires for solar cells, computer race track memory



Solid-State Microwave Power Module

Single module provides high performance radar, communications, navigation

Glenn Research Center engineers have developed a microwave power module (MPM) to power radar, communications, or navigation, interchangeably. This high-efficiency, all-solid-state MPM is based on a multi-stage distributed-amplifier design capable of very wideband operation. The module is extremely durable and can last a decade or longer. Already more compact and lightweight than conventional designs, Glenn's further reduces size by eliminating the need for both a traveling-wave tube amplifier and its accompanying kilovolt-class power conditioner. It has a much higher cut-off frequency and maximum frequency of oscillation than metal-semiconductor field-effect transistors and much faster pulse rise times. It can operate in both pulsed and continuous wave modes.

Typically, MPMs lack the linearity and efficiency needed for communications. Traditional MPMs require both a solid-state amplifier at the front end and a microwave vacuum electronics amplifier at the back end. Glenn's design features a much more efficient amplifier system.

The radar functions as a scatterometer, radiometer, and synthetic aperture imager. The high-speed communications system down-links science data from Earth-observing instruments. The navigation system functions like a transponder for autonomous rendezvous and docking, and estimates the range information. Glenn's MPM allows the use of a single power module to drive not only radar and navigation but also communications systems.

Benefits

- Wide bandwidth, amplifying radio frequency signals from 2 to 40 gigahertz
- High efficiency, operating in both pulsed and continuous wave modes
- High output power with reliable performance in high radio frequency ranges
- Compact and lightweight
- Radiation resistance

Applications

- Commercial and military satellite communications
- Military radar systems
- Phased-array antenna systems
- Aerospace radar, communications, navigation

Goddard

Green Precision Cleaning

Volatile-organic-compound-free system for tube and pipe cleaning

Goddard Space Flight Center scientists have developed a novel, volatile-organic-compound-free system for cleaning tubing and piping that significantly reduces cost and carbon consumption. The innovative technology enables the use of deionized water in place of more costly isopropyl alcohol (IPA) and does not create any waste, for which costly disposal is usually required. It uses nitrogen bubbles in water, which act as a scrubbing agent to clean equipment. The cleaning system quickly and precisely removes all foreign matter from tubing and piping.

NASA's Precision Green Cleaning invention was developed to clean flight tubing. The technology has potential to be useful to industries where IPA is commonly used to clean tubing and piping, or potentially where other water-cleaning applications are used. Such industries may include aerospace, pharmaceutical, bioprocessing, and food and beverage. Precision Green Cleaning may also be used to clean microelectronics equipment, parts, and surfaces.

Benefits

- Portable, eco-friendly design
- Cleaning effectiveness equal to or better than IPA processes
- Low cost through elimination of the need for IPA and waste disposal

Applications

- Replacement for IPA in tube and pipe cleaning
- Other water cleaning applications
- Aerospace, pharmaceutical, bioprocessing, and food and beverage industries
- Cleaning microelectronics equipment, parts, and surfaces

Low-Cost, Low-Temperature Radiometer for Thermal Measurements

In-situ sensing for long-wavelength infrared radiation

Many present and future NASA missions require high-performance, large-scale cryogenic systems, such as the sunshields and cold instruments for the James Webb Space Telescope. Testing these systems is problematic due in part to the low heat loads allowed. Heat loads can be influenced by black-body characteristics of the test chamber and stray heat from warmer parts of the system and ground support equipment. Previously, stray heat was not directly measured but inferred from deviations in the expected results, which led to errors. Technologists at Goddard Space Flight Center have developed a radiometer to help identify sources of stray heat and make noncontact thermal emission measurements of materials such as vapor-deposited aluminum on insulation, as well as background measurements of chamber effects such as light leaks and radiation bounces.

The radiometer is a simpler, much cheaper, and more flexible version of infrared detectors that have been used for high-resolution astronomical observations. Its form is similar to bolometers, which have long been used for sensitive astronomical infrared measurements. By relaxing the sensitivity and response times, the radiometers can be made much less costly.

Benefits

- Low cost
- Compact size
- Easy to calibrate
- Capable of high-resolution measurements

Applications

- In-situ sensing for long-wavelength infrared radiation
- Looking for heat leaks and reflected flux in low-temperature thermal vacuum systems

JPL

Portable, Rapid, Quiet Drill

Handheld drilling device for quiet drilling operations

A new handheld drilling device, suitable for a variety of operations and developed by the Jet Propulsion Laboratory (JPL), is portable, rapid, and quiet. Noise from drilling operations often becomes problematic because of the location or time of operations. Nighttime drilling can be particularly bothersome. Additionally, the use of hearing protection in the high-noise areas may be difficult in some instances due to space restrictions or local hazards. JPL's handheld drill is capable of effectively and efficiently drilling hard surfaces while remaining quiet enough to permit drill operation without the use of hearing protection.

The device includes a housing, a piezoelectric transducer, a rotating motor component, and a rigid cutting end-effector. As the motor component rotates within the housing and imparts rotational movement to the cutting end-effector, the piezoelectric transducer imparts axial movement to the end-effector. The end-effector includes a removable and replaceable drill bit. It can form a central borehole, and a compressor can be connected to this borehole to flush out dust, powder, or other bits during operation. The drill operates at noise levels that permit it to be operated without hearing protection.

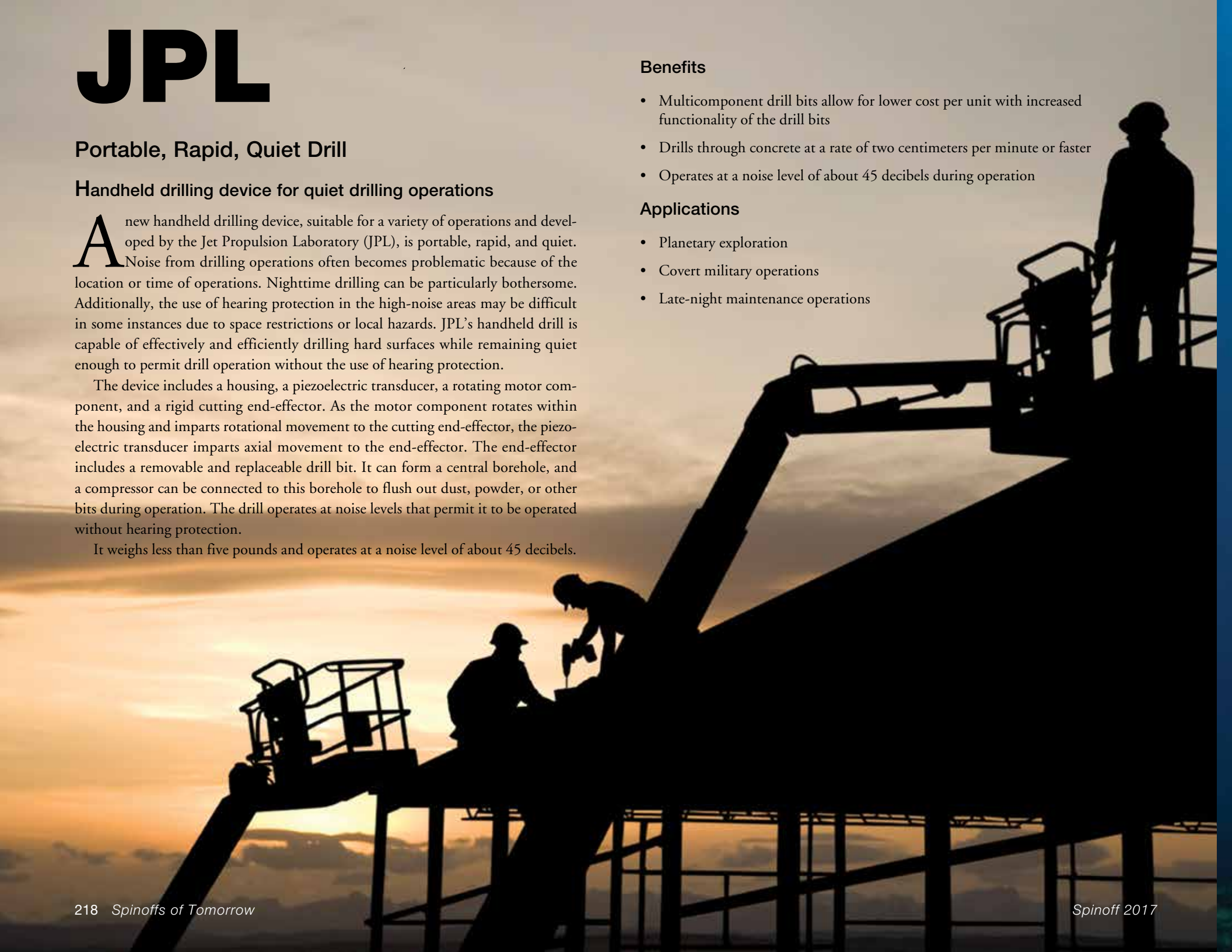
It weighs less than five pounds and operates at a noise level of about 45 decibels.

Benefits

- Multicomponent drill bits allow for lower cost per unit with increased functionality of the drill bits
- Drills through concrete at a rate of two centimeters per minute or faster
- Operates at a noise level of about 45 decibels during operation

Applications

- Planetary exploration
- Covert military operations
- Late-night maintenance operations



Underwater Vehicle Propulsion and Power Generation

The vehicle uses thermally generated buoyancy changes to generate power

The Jet Propulsion Laboratory (JPL) has developed an underwater vehicle that uses thermally generated buoyancy changes to generate electricity and recharge batteries, enabling it to remain underwater for years at a time. Like many cutting-edge underwater vehicles, it's propelled by temperature differentials in ocean water. Unlike conventional vehicles, however, JPL's extracts energy from the vehicle's gliding movement by turning a propeller turbine while in motion, recharging the batteries. The propeller can be turned off to reduce drag, and it can be used to drive the vehicle faster than would be possible with thermal gradients alone.

It includes a shaft with a propeller, an electric motor, a battery, and a controller. The controller optimizes the operating mode: charge, propulsion, or idle. When the vehicle glides, the propeller is forced to move. In charge mode, the propeller and rotor move while the motor acts as a generator, sending power to the battery. In propulsion mode, the current in the engine is reversed so it acts as a motor, driving the shaft and propeller. In idle mode, the motor circuit is open such that the propeller is freely turning, with negligible drag on the vehicle.

Benefits

- Reduces maintenance, retrieval, and refitting costs by allowing autonomous vehicles to stay underwater for years at a time
- Renewable source of electrical power for propulsion, communication, and scientific instruments
- Propeller acts as a combination turbine and motor, providing both propulsion and power generation

Applications

- Ocean study
- Earth sciences
- Underwater surveillance

Johnson

Self-Contained Device to Isolate Biological Samples

Pipette-free fluidic system enables easy DNA and RNA isolation outside laboratory

Innovators at Johnson Space Center have developed a self-contained device for isolating DNA, RNA, proteins, and cells without using pipettes or centrifuges. Composed of reagents, functionalized membranes, and multi-way valves and pumps, this novel fluidic system enables automation of accurate, real-time polymerase-chain-reaction (PCR) technology to isolate genetic material from organisms and microorganisms for molecular analysis. The device is self-enclosed and leak-proof, so users are protected from chemically hazardous reagents. Developed for use on the International Space Station, this easy-to-use tool can be automated and programmed, extending laboratory isolation protocols to numerous applications in healthcare, forensics, and field biology. It is also advantageous where hazardous chemicals must be confined to an enclosed container, such as military settings and remote clinical operations.

The pre-filled reagents are the same as those used in conventional PCR laboratory isolation analysis. Multiple kits can be stacked to allow several samples to be processed simultaneously. The system can be used in conjunction with existing analysis modules, such as commercially available DNA instruments. The process can be fully automated and programmed and can potentially be applied to other biological processes. The innovation will permit the extension of laboratory isolation protocols to many applications.

Benefits

- Compact and portable
- Self-contained, requiring no auxiliary equipment
- Protects users from chemically hazardous reagents
- Offers sensitivities similar to standard isolation methods

Applications

- Remote clinical operations
- Arctic operations
- Forensic investigations
- Agribusiness
- Space vehicles

Robotic Inspection System for Deep-Sea Structures

Determines volume of contents, structural integrity, and displays real-time video and sonar

Johnson Space Center innovators have designed a robotic inspection system capable of surveying deep-sea structures such as pipelines and oil platform storage cells and tanks to determine the volume of material remaining inside and the structure's integrity. The system displays real-time video and sonar. The device could significantly reduce the cost of inspecting and, potentially in the future, providing samples of a structure's contents. The technology is an all-in-one inspection device that includes cameras, sonar, and motion-sensing instruments with hardware and software components.

Generally, oil platforms include pipelines and subsea storage cells. The storage cells provide not only a stable base for the platform, but also intermediate storage and separation of oil. Surveying these structures to examine the contents is often required when the platforms are being decommissioned. The robotic inspection system is able to move through interconnected pipes, even making 90-degree turns, with minimal power. The device is able to display three-dimensional range data from two-dimensional information. This method and device could significantly reduce the cost of decommissioning cells, and future developments may additionally enable sampling of sediment or oil.

Benefits

- Three-dimensional sonar display from two-dimensional information
- All-in-one inspection device, including cameras, sonar, and motion-sensing instruments
- Minimal moving parts

Applications

- Sub-sea oil and gas platform structures
- Deep-sea exploration
- Pipelines containing fluids

Kennedy

Damage Detection System for Flat Surfaces

Multidimensional system for detecting damage to surfaces and vessels

Kennedy Space Center has created a damage detection system for flat composite surfaces. The ability to detect damage to surfaces can be crucial, especially on a sealed environment that sustains human life or critical equipment. Minor damage from foreign objects can eventually compromise a shell, resulting in failure. The ability to detect and locate damage lets technicians predict a system's lifetime and initiate repairs to prevent failure or extend the structure's life.

The system comprises layered composite material made up of thin film damage detection layers separated by thicker, nondetection layers, coupled with a detection system. The damage detection layers are thin films with a conductive grid that can be applied on various substrates using several methods. The number of detection layers in the material can be tailored to the level of detail needed. When damage occurs to any detection layer, a change in the electrical properties of that layer is wirelessly reported. Multiple damages can be detected simultaneously, providing real-time detail on the depth and location of damage. Individual detection layers can be turned on or off, and algorithms can be modified to optimize performance. The system can be used to generate both diagnostic and prognostic information.

Benefits

- Precisely locates damage so repairs can be initiated when needed to prevent failure
- Modular design allows damaged surfaces to be easily replaced
- Individual detection layers can be turned on or off to collect information as needed
- Conductive pattern can be applied on various materials using multiple methods, customizing size, shape, and thickness
- Enables prediction of the remaining expected lifetime of composite system

Applications

- Aircraft
- Military shelters
- Solar arrays
- Critical hardware enclosures
- Spacecraft and space habitats
- Inflatable structures
- Smart garments

In-Situ Wire Damage Detection and Rerouting System

Miniaturized and highly efficient wire damage detection system

Kennedy Space Center engineers have invented an in-situ wire damage detection and rerouting system. It consists of a miniature inline connector containing self-monitoring electronics that use time-domain reflectometry to detect wire faults and determine fault type and location on electrical wiring. When a damaged or defective wire is identified, the system can autonomously transfer power and data connectivity to another wire. Used in conjunction with NASA's conductive detection layers, the system can detect and limit damage not only to the core conductor but also to the insulation layer before the conductor is compromised.

The tester monitors electrical faults in either online or offline modes. In online mode, wires are monitored without disturbing their operation. A cable can be monitored several times per second in offline mode and once per second in online mode. The online fault locator not only detects the occurrence of a fault, but also determines its type and location. This enables detection of intermittent faults that can be repaired before they become serious problems. Since these occur mainly during operations, a memory device stores all relevant data. Data can be displayed in real time or retrieved later.

Benefits

- Can be used while wires are operational to locate intermittent faults
- Uses low power signals that do not disrupt normal circuit operation
- Autonomously identifies type and location of a fault
- Easy-to-understand graphical user interface
- Can monitor up to 64 wires on a cable

Applications

- Aerospace wiring
- Marine wiring
- Automotive wiring
- Industrial wiring
- Smart grid wiring

Langley

Convective Heating Improvement for Emergency Fire Shelters (CHIEFS)

Improved performance of emergency fire shelters for wildfire fighters

Langley Research Center is developing Convective Heating Improvement for Emergency Fire Shelters (CHIEFS) to improve the performance of emergency fire shelters for wildfire fighters. A fire shelter is a last-resort safety measure that may protect firefighters trapped by fire. The current shelter design, resembling a small foldable tent, is primarily designed to protect the user from exposure from radiant heat. It provides limited protection when exposed to direct flame. The Washington Office of Fire and Aviation Management initiated a product review for the fire shelters to be completed by 2018. NASA is working closely with U.S. Forest Service to understand emergency fire shelter requirements and testing procedures.

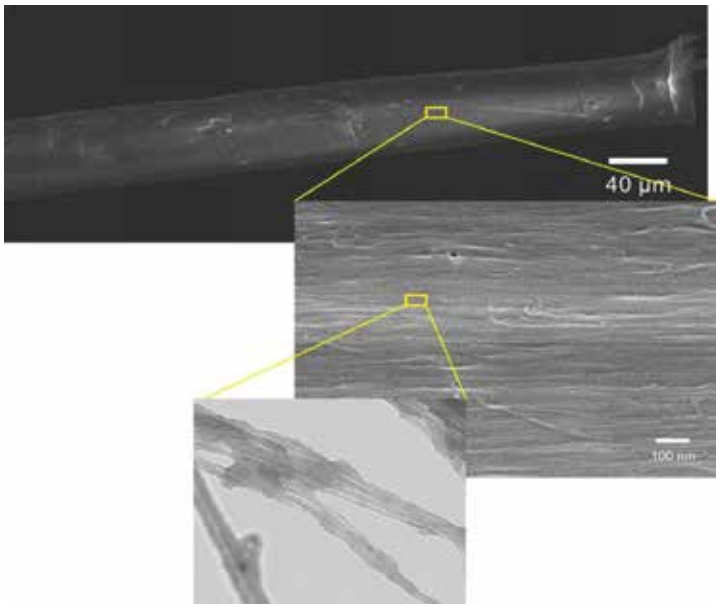
The CHIEFS material will use technology drawn from a new spacecraft flexible heat shield NASA is developing for planetary missions. By modifying this material, using heat-shield test methods, and experimenting with different structures, the team is improving thermal performance while minimizing any increase in weight and packed volume. To protect against radiant heat, the exterior uses a laminate that reflects over 90 percent of radiant heat from a fire. To protect against convective heat or direct flame, the interior has high-temperature insulation layers and a gas barrier layer to keep hot gasses from entering.

Benefits

- Based on flight-tested NASA technology
- Optimized for manufacturability and packing
- Capable of withstanding temperatures up to 3,000 °F
- Lightweight

Applications

- Wildfire fighting
- First responders



Sucrose-Treated Carbon Nanotube and Graphene Yarns and Sheets

Cost-effective method to create carbon nanotube and graphene yarns and woven sheets

Langley Research Center has developed a method to create yarns and woven sheets from carbon nanotubes and graphene through the dehydration of sucrose. The resulting materials are lightweight and strong. Sucrose is inexpensive and readily available, making the process cost-effective.

Various aerospace and terrestrial applications require lightweight materials with very high mechanical properties. Carbon nanotubes and graphene sheets have such characteristics, and they have excellent electrical and thermal transport properties. However, retaining these properties in bulk materials has proven challenging. For nanotubes to be used, they must be spun into yarns, sheets, and other large forms, introducing weak tube-to-tube and inter-bundle bonds. Also, the nanotubes tend to be tangled and therefore do not all contribute to load bearing. Weak coupling at tube and bundle interfaces also leads to mechanical and thermal transport properties that are much lower than would be expected from nanoscale carbon nanotubes or graphene.

This method consolidates carbon nanotube or graphene into yarns and woven sheets through the formation of a carbon binder formed from the dehydration of sucrose. The resulting materials are lightweight, stiff, and strong.

Benefits

- Produces materials with greater than 30 percent increase in tensile properties compared to starting materials
- Method uses an inexpensive base material—sucrose—for the manufacturing process
- Dielectric and electrical properties of the yarns and sheets can be tailored

Applications

- Structural materials for aerospace vehicles
- Materials for lightweight, mechanically robust consumer devices
- Materials for space habitats

Marshall

Digital Machine Control Electronics

Position sensors, switches, controllers, and communications electronics for robotic assembly

Marshall Space Flight Center has a suite of novel technologies for digital control of machinery. NASA developed the technologies for autonomous assembly of space structures. The base technologies can improve gap sensors and absolute position sensors. They wirelessly communicate position and proximity to drive switching and stepper motor operations. Other technologies in the suite can be incorporated to perform additional sensor functions and serve as a short-range antenna and close-proximity transmitter and receiver. The technologies are self-calibrating and have embedded integrity monitoring functions for assured position and proximity readings.

For positioning and gap sensing, Marshall has the Single Coil Absolute Position Sensor (SCAPS) and Inductive Gap Sensor (GAPSYN) Digital Signal Conditioning Electronics suite. An Absolute Limit Switch determines an absolute limit switching point, such as to stop a movable carriage. A linear feedback sensor system senses the position of a rotor in a hybrid stepper motor. The Micro-Commanding Servo Motor Controller with Greater than 50 Million to One Dynamic Rate Range senses rotary position of a drive shaft to derive appropriate drive signals for a motor. The Short Range Antenna/Close Proximity Transmitter and Receiver is an inexpensive, effective method of exchanging information over a short distance between two devices.

Benefits

- Simple, inexpensive components
- Enables absolute position and improved precision compared to conventional techniques
- Provides precise control for multi-phase stepper motors
- Same hardware can be used for measuring and communicating
- Small footprint allows operation in small spaces, perhaps miniature applications

Applications

- Computerized numerical control, water jet, and laser milling machines
- Pick and place machines for semiconductor manufacturing and automated biotech operations
- Hard disc drives, printers, and scanners
- Rotary and linear positioning of automotive engine components
- Profilometers
- Industrial robots in which raster, head, and substrate are in close proximity
- Robot-assisted surgery

Image courtesy of Matt Wade, CC BY-SA 3.0.

Ultrasonic Stir Welding

New solid-state weld process for better weld quality and longer tool life

Marshall Space Flight Center developed ultrasonic stir welding to join large pieces of very high-strength, high-melting-temperature metals such as titanium and Inconel. This weld process improves current thermal stir welding by adding high-power ultrasonic (HPU) energy at 20 kilohertz. The addition of ultrasonic energy reduces axial, frictional, and shear forces; increases travel rates; and reduces wear on the stir rod, extending its life. The process decouples the heating, stirring, and forging elements of friction stir welding, allowing for independent control of each process element and greater process control and repeatability. With independent control of process elements, closed-loop temperature control can maintain a constant weld nugget temperature.

A stir rod stirs the plasticized abutting surfaces of two pieces of metal that form the weld joint. Heating is accomplished with a specially designed induction coil. The control system can pulse HPU energy of the stir rod on and off at different rates from one-second pulses to 60-millisecond pulses. This pulsing capability allows the stir rod to act as a mechanical device, stirring the plasticized material, when the HPU energy is off, and allowing the energized stir rod to transfer HPU energy into the nugget, reducing forces and increasing stir rod life, when HPU energy is on.

Benefits

- Improved weld properties
- Increased tool life (stir rods, bushings, containment plates)
- Automated closed-loop feedback control
- Potential for integration into robotic welders
- Reduced axial and shear consolidation forces
- Potential for handheld version
- Reduced friction without lubricants

Applications

- Aerospace hardware for severe environments, launch vehicles, aircraft
- Automotive pistons, struts, vehicle structure
- Marine shipbuilding, platforms
- Civil bridges, trains, pressure vehicles

Stennis

NASA Data Acquisition System Software Suite

Software acquires, processes data from various hardware platforms

NASA Data Acquisition System (NDAS) is a modular, extensible data acquisition and processing software suite that provides a common user interface across different hardware platforms. Stennis Space Center requires reliable data to analyze results of rocket engine tests. Acquisition systems include high-speed data, low-speed data, event monitoring, and video feeds. Calibrations must be performed on each measurement channel, including the entire hardware chain, from signal acquisition to signal conditioning and digitization. The NDAS suite processes sensor data and then scales it to engineering units. Flexibility and modularity enable use on a wide range of hardware and test facilities.

The suite is designed to operate and control critical aspects of rocket engine tests and provide accurate data. A common user interface across different hardware platforms improves consistency and reduces errors.

NDAS is primarily written in LabVIEW, a graphical, data-flow-driven language, and makes use of a new development framework called the Actor Framework. It provides a level of code reuse and extensibility previously difficult to achieve with LabVIEW. The design allows the software to be ported to multiple facilities with no modifications to the design and minimal modifications to the code.

Benefits

- Reduced measurement uncertainty, provides traceability
- Flexible, with multiple output and input formats, expandability, non-hardware-specific database
- Standard interface and work flow for multiple text fixtures and engine programs
- Adaptable to different acquisition systems with minimal effort
- Separate modules simplify maintenance and life cycle support
- Data output files and displays can be customized to a variety of uses, and new output types and display tools can be added
- System, measurements, calibrations are managed, configured in a common user interface
- Run-time processing and analysis minimizes post-test data processing turnaround time

Applications

- Rocket engine propulsion tests
- Any other data acquisition application using scientific measurement data

Traceable Gas Standards for Aerospace Community

New standards to improve safety margins and performance

National Institute of Standards and Technology (NIST) traceable gas standards do not exist for evaluating impurities in propellants and pressurants used for rocket propulsion. Standards for identical gas blends frequently disagree, causing conflicting analysis results. Stennis Space Center developed an approach for an NIST traceability technique for analyzing gasses in propellants. Calibration response factors for each target gas were developed using a gas chromatograph with a thermal conductivity detector. These factors were used to establish a calibration relationship to methane or carbon monoxide, which are NIST-traceable. By using an NIST-traceable gas standard as the predictor for other gasses, systematic error is reduced from 15-80 percent to below 10 percent.

Thermal conductivity of gas constituents are unique and fixed. Accurate quantification requires establishing calibration response factors relative to a known gas reference. The method developed determines a relative response value between methane or carbon monoxide for each permanent gas.

By establishing calibration response factors to an NIST standard, NASA and the aerospace industry can measure each gas component with NIST traceability. This eliminates the need to crosscheck and evaluate multiple gas standards, ensuring process consistency and increased confidence in data quality with reduced costs.

Benefits

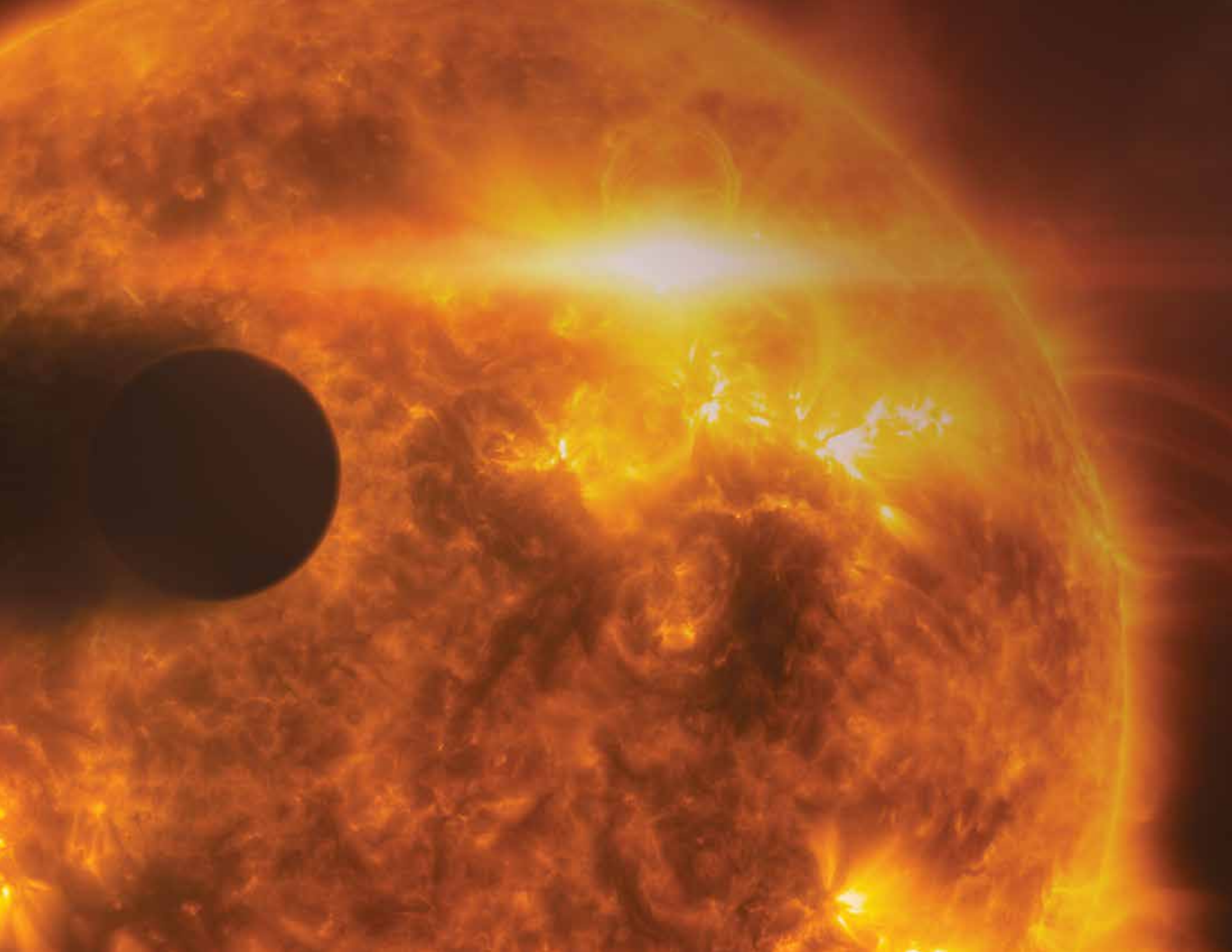
- Improved margin of safety in propellant/pressurant systems
- Data Sensitivity, laboratory validation, accurate and reliable processes
- Consistent method for monitoring impurities in propellants and pressurants
- Traceable gas standard for aerospace community, improved performance and measurement capability
- Less process variation means improved performance

Applications

- Military certification of propellants, pressurants
- Commercial space industry
- Semiconductor industry
- Nuclear power industry

NASA's Technology Transfer Program

Formally established in 1962, NASA's Technology Transfer Program is the Agency's oldest continually operated mission. Its goal is to inject NASA research, technology, and inventions into American industry as much as possible, whether by publishing new discoveries, patenting and licensing valuable inventions, or collecting and distributing software codes.



NASA's Technology Transfer Program

Bringing NASA technology down to Earth

When Congress enacted the National Aeronautics and Space Act in July 1958, the country was facing a crisis. Just months prior, the Soviet Union had shocked the world with the successful launch of Sputnik 1, the first artificial satellite to attain orbit. Sputnik 2 followed a mere 32 days later, carrying with it Laika—a stray dog from the streets of Moscow—eliminating doubt that human beings could survive the ride into space. Amid growing tension between the Cold War rivals, President Eisenhower pushed the U.S. satellite program to send its own orbiter to space months ahead of schedule. By the time Explorer 1 successfully launched from Cape Canaveral on February 1, 1958, the Space Race had begun in earnest.

But even against this background of urgency, the Space Act embodied a long-term approach to space exploration, declaring U.S. policy to be "that activities in space should be devoted to peaceful purposes for the benefit of all mankind" and that NASA would "provide for the widest practicable and appropriate dissemination" of the results of its missions. In this provision, Congress anticipated that the benefits of space technology would be diverse and open-ended, extending far beyond the national pride at stake in the Space Race.

For more than half a century since, NASA's Technology Transfer Program has played a crucial role in repaying the Nation's investment in space and aeronautics research with tangible benefits for industry and consumers in virtually every sector of the economy.

Today, the program processes more than a thousand new technologies created at NASA each year and publishes reports on hundreds of them. Of those, more than a hundred are patented annually and join a portfolio of about a thousand inventions available for licensing by U.S. industry. Program specialists also maintain a repository of more than a thousand software codes—nearly all of which are available free of charge.

Members of NASA's Technology Transfer Program leadership team, gathered in Portland, Oregon, in June 2016.

NASA's rate of technology transfer has even increased in recent years. "In October of 2011, President Obama called on all Federal agencies to develop a plan to accelerate technology transfer activities," says Daniel Lockney, executive of NASA's Technology Transfer Program. "In response, NASA found ways to reduce policy hurdles and amplify our interactions with industry. In four years, we've managed a 250 percent increase in annual patent licensing and a 100 percent increase in releases of software to the public.

"The end product of these technology transfers are spinoffs that spur economic growth and improve the lives of people worldwide," Lockney adds.

Among the nearly 80 licenses executed with industry in the past year are inventions big and small. One technology, originally devised to keep astronauts safe during the rigors of rocket launches, can now be found stabilizing a skyscraper in Brooklyn and might soon find its way into new construction across the country (see page 72).

"Our vibration damper is a great example of how NASA inventions can make a big impact outside the Agency," says Terry Taylor, chief of Marshall Space Flight Center's Technology Transfer Office, who oversaw licensing negotiations for the device. "An engineering challenge in rocket science led to a brand-new technology—technology that can strengthen buildings and save lives."

In addition, new program initiatives launched in late 2015 and 2016 have helped attract broader interest in NASA technology:

SPACE RACE

ENGAGE. COMPETE. LAUNCH.

- **Startup NASA:** An innovative price structure for new businesses, Startup NASA allows high-tech entrepreneurs to turn NASA inventions into viable commercial products with as few barriers as possible. New companies pay nothing up front to license a NASA technology and have no minimum payements for three years. "We wanted to make it painless for people to take NASA inventions and start new companies with them," says Lockney. "Startup NASA lets these innovators secure intellectual property and hold onto their cash—two of the biggest challenges startups face." In just its first year of operation, the Startup NASA initiative resulted in 20 startups applying to license NASA technology.
- **Space Race:** Also aimed at startups, Space Race is a competition and business accelerator for teams of entrepreneurs looking to turn NASA technologies into new products. Co-managed with the Center for Advancing Innovation, the contest selected 11 NASA patents with particular commercial promise. Participants developed elevator pitches for commercial applications and worked with business experts to develop robust business plans. The winners received cash prizes, and finalists will also have the opportunity to pitch their ideas to a panel of independent investors who are willing to commit up to $1.2 million in seed funding for deserving candidates. Following the event, more than a dozen new companies are expected to form and license NASA technology.
- **Gift to the Public Domain:** Not all NASA technologies must be licensed to be used. In addition to the huge repository of free software the Technology Transfer Program manages and makes available, in 2016 the program also expanded the portfolio of inventions that have been gifted into the public domain. In May, NASA announced that it was disclaiming 56 patents, which joined a newly available database of thousands of other formerly patented technologies now offered for unrestricted commercial use.

  Most of these technologies relate to spacecraft systems, such as propulsion and life support, and they could find use among emerging commercial space companies. Lockney says this NASA offering is reminiscent of the Agency's earliest days, when NACA (the aeronautics agency that eventually became NASA) played a key role in the development of commercial aviation, lending its expertise to advance the entire industry.

That decades of NASA research has ongoing relevance to one of today's most cutting-edge industries freshly demonstrates Congress' foresight in mandating that the results of the Space Agency's work be shared as widely as possible. When placed in the hands of capable businesses, NASA technology continues to fuel new companies, create jobs, generate revenue, save on costs, and enhance public safety. It finds its way into new products and services that repay American taxpayers for their investment in space. ❖

The Space Race Competition, co-managed by NASA and the Center for Advancing Innovation, centered on 11 specially selected NASA technologies with commercial promise. These included a robot capable of digging in low- and no-gravity environments, top; a kite-like system that generates electricity from wind power, middle; and a lightweight sensing and control system for unmanned aerial vehicles that permits semi-autonomous flight.

Technology Transfer Program Network Directory

Bringing NASA Technology Down to Earth

NASA's Technology Transfer Program pursues the widest possible applications of Agency technology to benefit U.S. citizens. Through partnerships and licensing agreements with industry, the program ensures that NASA's investments in pioneering research find secondary uses that strengthen the economy, create jobs, and improve quality of life.

To learn more about licensing NASA technology, visit http://technology.nasa.gov. General inquiries may be directed to the Spinoff Program Office at spinoff@nasa.gov. To suggest a story about a commercial product or service developed with NASA technology, assistance, or know-how, contact *Spinoff* at the email address above, or visit http://spinoff.nasa.gov.

NASA Headquarters provides leadership, policy, strategy, resource allocation, and media relations for technology transfer activities Agencywide.

Technology Transfer Program Offices at each of NASA's 10 field centers represent NASA's technology sources and manage center participation in technology transfer activities.

Allied Organizations support NASA's Technology Transfer Program objectives.

MAP KEY

NASA HQ — NASA Headquarters
ARC — Ames Research Center
AFRC — Armstrong Flight Research Center
FLC — Federal Laboratory Consortium
GRC — Glenn Research Center
GSFC — Goddard Space Flight Center
JPL — Jet Propulsion Laboratory
JSC — Johnson Space Center
KSC — Kennedy Space Center
LaRC — Langley Research Center
MSFC — Marshall Space Flight Center
SF — Space Foundation
SSC — Stennis Space Center
Tech Briefs — Tech Briefs Media Group

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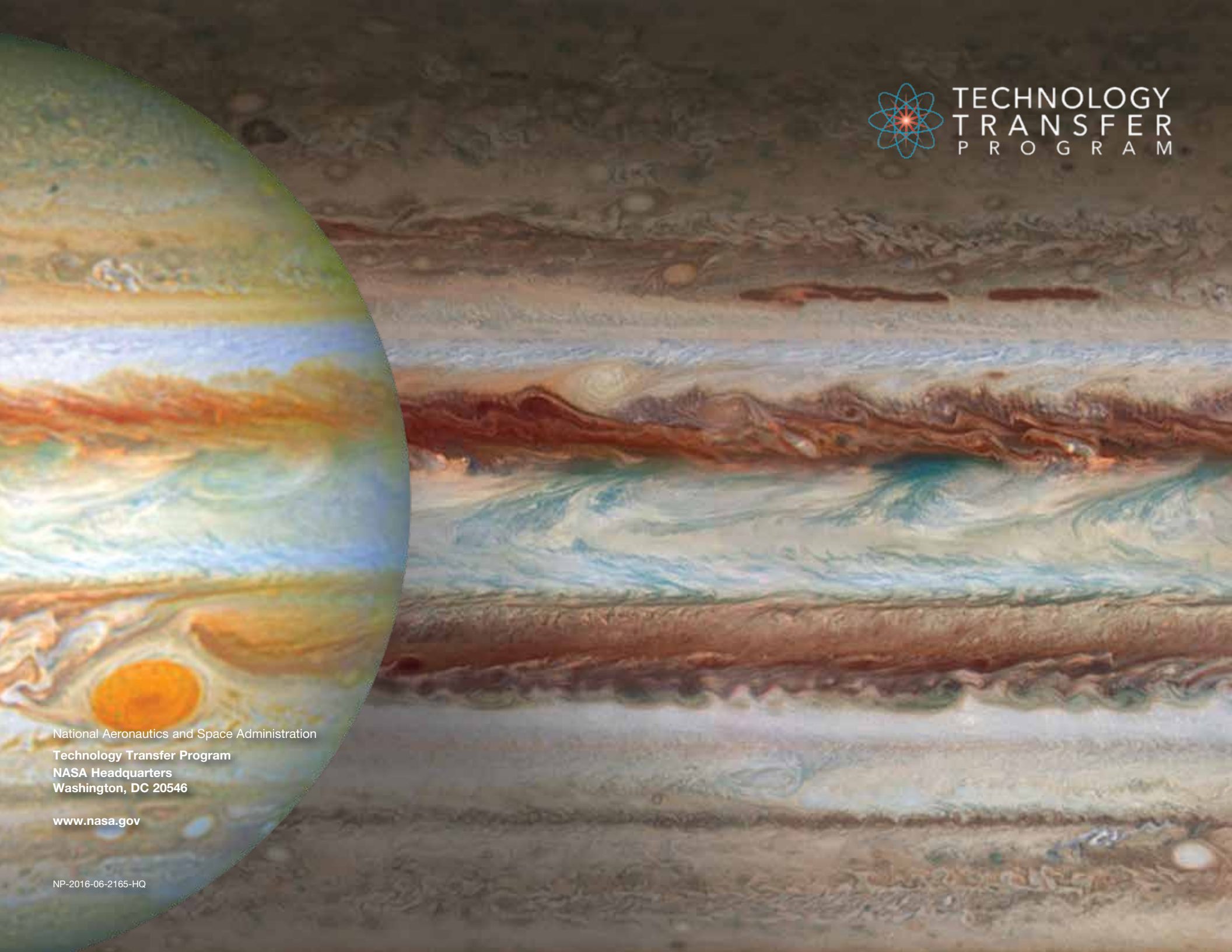

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